



MONASH University
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**THE INFLUENCE OF TRENDS IN
HEAVY VEHICLE TRAVEL ON ROAD
TRAUMA IN THE LIGHT VEHICLE
FLEET**

by

Amanda Delaney

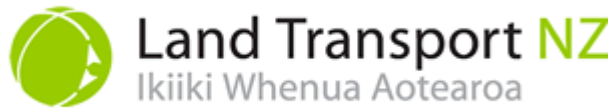
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Abstract:

Increased travel by heavy vehicles (rigid trucks, articulated trucks and buses) has been identified as one of the key components of total growth in vehicle travel to 2010. This study examines the effect of anticipated growth in heavy vehicle travel on road trauma in the light passenger vehicle fleet. Road trauma levels are measured by the number of light vehicle driver fatalities and serious injuries resulting from light passenger vehicle collisions with heavy vehicles.

Using exposure data sourced primarily from the BTRE and the ABS in conjunction with NSW Police reported crash database, a model to project relevant future trends in road trauma has been developed to reflect three key elements of the road trauma chain: exposure, crash risk and injury outcome given crash involvement. In addition to the specific results presented in this study, the model developed may be used to assess the likely impact of proposed policy changes on heavy vehicle related road trauma. Future heavy vehicle related road trauma trends are projected based on two scenarios of future crash risk. The results demonstrate the sensitivity of heavy vehicle related road trauma to crash risk and highlight the importance of continuing to reduce heavy vehicle crash rates to offset projected growth in heavy vehicle travel and deliver reductions in heavy vehicle related road trauma. A potential remedy to predicted increases in heavy vehicle related trauma is explored and demonstrates the application of the model as a policy evaluation tool.

Key Words:

Heavy vehicles, crashworthiness, safety, passenger vehicles

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Preface

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EXECUTIVE SUMMARY

INTRODUCTION

Increased travel by heavy vehicles has been identified as one of the key components of total growth in vehicle travel to 2010. Given the obvious incompatibility between heavy vehicles and the light passenger vehicle fleet in crash situations, the anticipated rise in heavy vehicle travel raises questions about the likely impact on road trauma levels should the anticipated increases be realised. This study aims to examine the effect of anticipated growth in heavy vehicle travel on road trauma within the light passenger vehicle fleet. Road trauma levels are measured by the number of light vehicle driver fatalities and serious injuries resulting from light passenger vehicle collisions with heavy vehicles.

The factors that likely influence total road trauma levels associated with heavy vehicle travel include: growth in heavy vehicle transport and the area of that growth (i.e. metropolitan or non-metropolitan), the relative seriousness of outcomes in light passenger vehicle collisions with the three heavy vehicle types, differences between crash outcomes in metropolitan and non-metropolitan areas and changes in heavy vehicle crash rates due to improved safety of both vehicle and non-vehicle infrastructure. The influence of each of these factors is considered in the model used to estimate total road trauma levels within the light passenger vehicle fleet.

DATA

To reflect the detail available in the data for analysis, heavy vehicles were defined in three classes: articulated trucks, rigid trucks and buses. Data detailing the nature and extent of travel undertaken by these vehicle types and the frequency of crashes in which they are involved are derived from three sources. Estimates of national vehicle kilometres travelled by commercial vehicles (including buses) were provided by the Bureau of Transport and Regional Economics (BTRE). The Australian Bureau of Statistics (ABS) Surveys of Motor Vehicle Use provide data detailing average annual vehicle kilometres travelled by vehicle type and average annual tonne kilometres by vehicle type for the years 1998 to 2003. Finally, NSW Police reported crash data covering crashes resulting in death, injury or a vehicle being towed away between 1990 and 2003 was used in conjunction with vehicle information supplied by the New South Wales Roads and Traffic Authority (RTA) to estimate the frequency of collisions involving articulated trucks, rigid trucks or buses. The data also generates the distribution of heavy vehicle crashes by the opposing light passenger vehicle market group and is used to produce revised estimates of the aggressivity of heavy vehicles towards light passenger vehicles categorised into distinct market groups.

Monthly distillate fuel sales data for the period 1991 to 2004 provided for each State and Territory by the Federal Department of Industry, Science and Resources was used to scale NSW crash data to generate estimates of national heavy vehicle crashes.

MODEL INPUTS

Historical trends in heavy vehicle travel and crashes are important inputs into the model of total road trauma. Considering Australia-wide heavy vehicle travel, during the early 1990s there was a period of decline in total annual travel by both rigid trucks and buses, most likely associated with the economic recession at the time. Travel by articulated trucks

remained stable over this period. Over the next decade, travel across all heavy vehicle classes increased steadily although the rate of growth varied across vehicle types. This upward trend in heavy vehicle travel represents an increase in exposure to crash risk.

There is broad correspondence between growth in heavy vehicle travel and the number of heavy vehicle crashes over the period examined. The noted decline in rigid truck and bus travel and stable levels of articulated truck travel in the early 1990s was associated with a decline in the number of crashes involving each of these heavy vehicle types. Similarly, articulated trucks and buses experienced a rise in the number of crashes as travel increases. However, the number of crashes involving rigid trucks did not increase significantly as travel by that vehicle type increased.

Estimates of heavy vehicle travel and the number of heavy vehicle crashes are also provided separately for metropolitan and non-metropolitan areas in the full report. Using this data average total, metropolitan and non-metropolitan crash rates for the period 1998 to 2003 were calculated. These crash rates are presented in Table i below.

Table i. Average heavy vehicle crash rates per million vehicle kilometres travelled in metropolitan and non-metropolitan areas (1998-2003)

Heavy Vehicle Type	Metropolitan Crash Rate (a)	Non-metropolitan Crash Rate (b)	Relative Difference (a)/(b)	Total (c)
Articulated Trucks	5.76	0.87	6.62	1.75
Buses	6.57	0.52	12.63	3.26
Rigid Trucks	2.04	0.74	2.76	1.47

The greatest disparity between metropolitan and non-metropolitan crash rates was found for buses, followed by articulated trucks and rigid trucks. In metropolitan areas, buses had the highest crash rate followed by articulated trucks and rigid trucks whereas in non-metropolitan areas articulated trucks had the highest estimated crash rate followed by rigid trucks and buses. As these crash rates refer to collisions with light passenger vehicles only, potential explanations for the variations in the crash rates included differences in exposure to the light passenger vehicle fleet.

Crashworthiness

The risk of death or serious injury to light passenger vehicle drivers in collisions with heavy vehicles (vehicle crashworthiness) will also influence the safety impact of future growth in heavy vehicle travel. Crashworthiness estimates for light passenger vehicles in collisions with heavy vehicles by light market group and heavy vehicle class have been estimated using the most recently available data. It is evident from these results that the risk to light passenger vehicle drivers differs by both light passenger vehicle market group and the type of heavy vehicle involved. Articulated trucks pose the greatest risk of death or serious injury to drivers of all light passenger vehicle types for which estimates could be obtained. However, for crashes involving articulated trucks, statistically significant differences in the risk to drivers of the various light passenger vehicle market groups could not be identified. Drivers of light passenger vehicles colliding with rigid trucks and buses experience a similar rate of death and serious injury, however, the risk does differ

according to the market group of the light passenger vehicle. At particular risk are drivers of compact 4WDs, light passenger cars and small passenger cars. At significantly lower risk in collisions with rigid trucks are drivers of medium or large 4WDs and commercial utilities.

METHOD

Estimating a base level of road trauma

Using data from 1998 to 2003, three stages were used to determine the base level of road trauma related to heavy vehicle travel. The same approach was adopted to estimate road trauma levels in metropolitan and non-metropolitan areas respectively using data specific to these areas. The first step involved estimating the total national number of crashes involving each type of heavy vehicle. The second stage determined the distribution of heavy vehicle crashes by the light passenger vehicle collision partner and estimated the number of light vehicle driver casualties involved in each collision type. The distribution of heavy vehicle crashes by the light passenger vehicle collision partner was calculated as the average proportion of all heavy vehicle to light passenger vehicle collisions occurring in each heavy vehicle crash configuration (e.g. rigid truck vs. large passenger car) for the period 1998 to 2003 derived from the NSW heavy vehicle crash data. Total crashes involving the relevant heavy vehicle type were then multiplied by these proportions to estimate the number of drivers involved in each collision type in each year. The final stage used estimates of crashworthiness by heavy vehicle class and light passenger vehicle market group to calculate fatalities and serious injuries resulting from heavy vehicle crashes.

Forecasting levels of road trauma

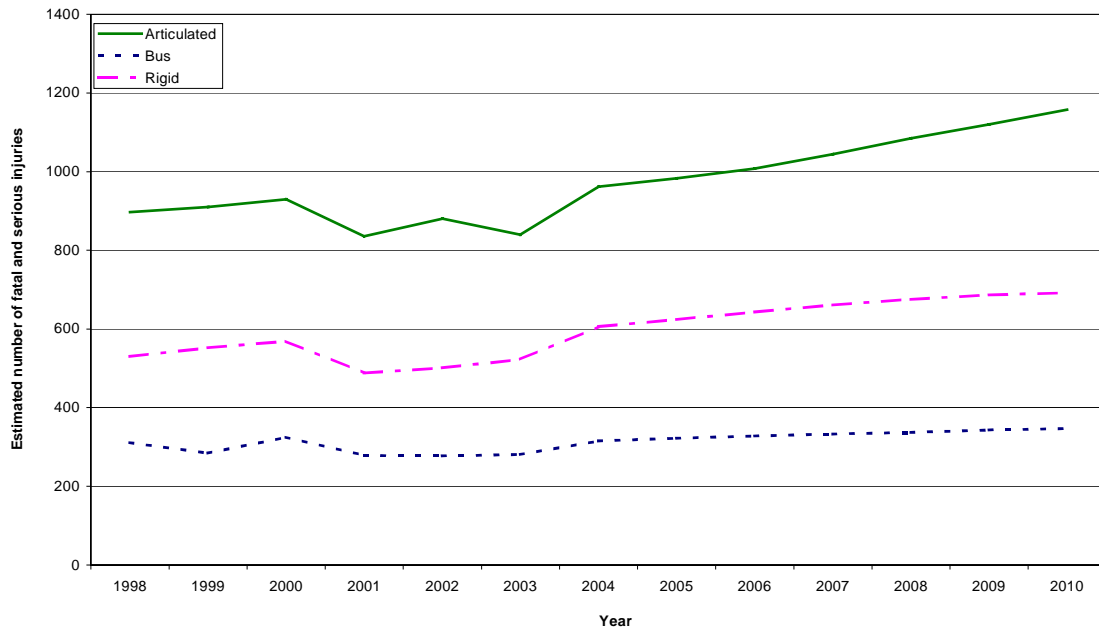
Using crash and exposure data from previous years, annual heavy vehicle crash rates were estimated and applied to the BTRE forecasts of future heavy vehicle travel to estimate the number of future crashes involving each heavy vehicle type. In applying a crash rate to future heavy vehicle travel a decision had to be made about which crash rate forecast to use. Two alternatives are presented in this paper. The first used crash rates for the period 1998 to 2003 to forecast crash rates for 2004 to 2010 using a linear trend. The second assumed that the crash rate remains stable at the 2003 levels over the period 2004 to 2010.

RESULTS

As noted above, two scenarios for forecasting future road trauma levels were investigated. The resulting estimates of road trauma differed according to the crash rates applied and when viewed together provided a range of potential future road trauma levels. As shown in Figure i, when assuming stable crash rates from 2003 onwards, there is evidence of predicted substantial increases in fatal and serious injuries resulting from light passenger vehicle collisions with each heavy vehicle type. The greatest increase predicted was generated by articulated truck travel. Although rigid trucks are forecast to travel more vehicle kilometres over the forecast period and the crash rates of the two vehicle types do not differ greatly, the average severity of crashes involving articulated trucks is approximately twice that of crashes involving rigid trucks. Therefore, the higher severity associated with articulated truck crashes appears to be the primary contributor to the higher number of fatalities and serious injuries associated with articulated truck travel. However,

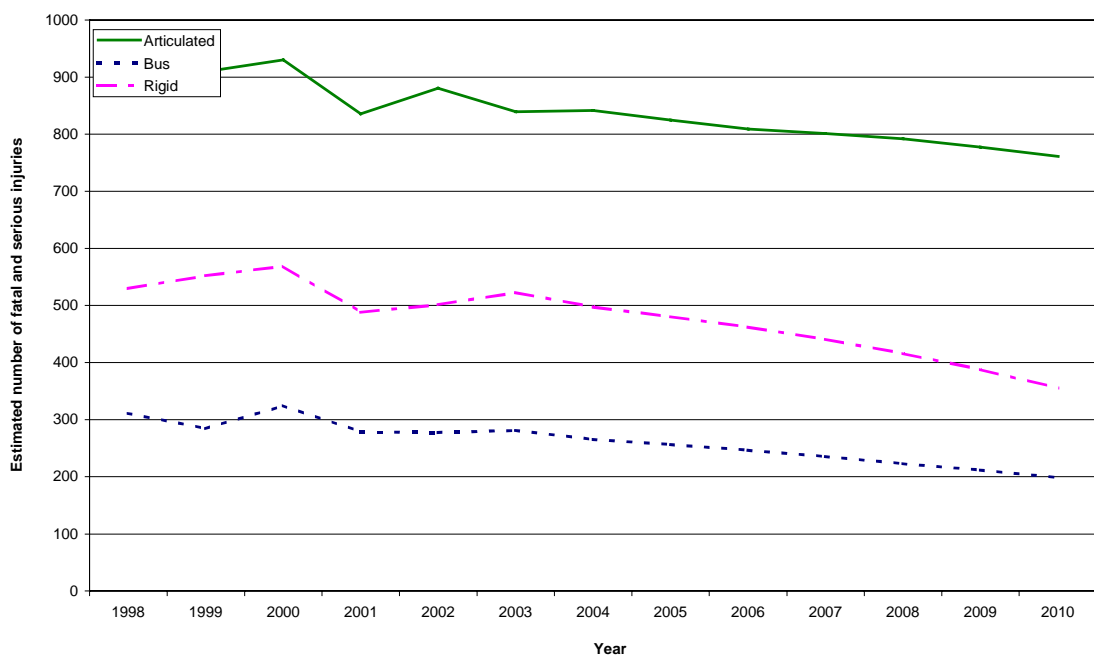
it is also noted that forecast percentage growth in vehicle travel is greater for articulated trucks than rigid trucks particularly in non-metropolitan areas.

Figure i. Estimated number of fatalities and serious injuries resulting from collisions between heavy vehicles and light passenger vehicles: 2003 crash rate maintained.



Under the alternative scenario, where crash rates for the three heavy vehicle types decline according to a linear trend over the forecast period, fatal and serious injuries resulting from light passenger vehicle collisions with each heavy vehicle type were predicted to decline slowly over the forecast period. Under this scenario, increases in heavy vehicle travel are more than offset by declining crash rates and fatal and serious injuries resulting from collisions with heavy vehicles were predicted to decrease over time despite increases in vehicle kilometres travelled.

Figure ii. Estimated number of fatalities and serious injuries resulting from collisions between heavy vehicles and light passenger vehicles: Linear forecast of crash rates.



Restricted Articulated Truck Travel

Given the relatively high crash rate experienced by articulated trucks in metropolitan areas and the relatively high severity of crashes involving articulated trucks, the impact of removing articulated trucks from the metropolitan area was considered. The workload of articulated trucks in metropolitan areas was transferred to rigid trucks through use of relative tonne-kilometre estimates for the two vehicle classes. The results are presented for the two crash rate scenarios in Figures iii and iv following.

Figure iii. Estimated number of fatalities and serious injuries resulting from collisions between heavy vehicles and light passenger vehicles where articulated truck travel is restricted to non-metropolitan areas: 2003 crash rates maintained.

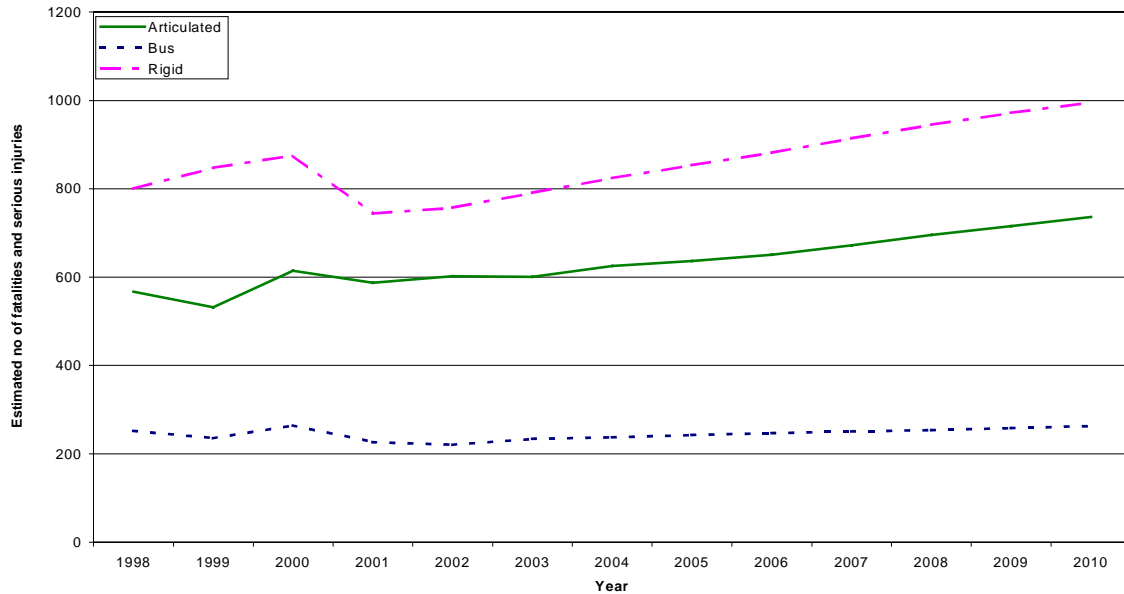


Figure iv. Estimated number of fatalities and serious injuries resulting from collisions between heavy vehicles and light passenger vehicles where articulated truck travel is restricted to non-metropolitan areas; Linear forecast of crash rates.



To quantify the potential benefits of restricting articulated truck travel to non-metropolitan areas, the percentage difference between the forecasts presented for combined metropolitan and non-metropolitan travel with no restriction on articulated truck travel and those with the restriction applied were compared. Percentage differences in the crash projections between the two scenarios are presented in Table ii.

Table ii. Estimated percentage crash savings due to the removal of articulated trucks from metropolitan roads: 1998-2010.

Year	2003 Crash Rate	Linear Forecast of Crash Rate
1998	3.63%	3.63%
1999	3.44%	3.44%
2000	-0.32%	-0.32%
2001	-1.19%	-1.19%
2002	2.65%	2.65%
2003	-1.58%	-1.58%
2004	-1.59%	-2.50%
2005	-1.59%	-3.97%
2006	-1.60%	-5.72%
2007	-1.61%	-7.87%
2008	-1.63%	-10.56%
2009	-1.64%	-13.94%
2010	-1.65%	-18.36%

NB: Negative values in the table indicate an estimated crash increase

DISCUSSION

This study has attempted to quantify the effects of projected growth in heavy vehicle travel on the future levels of road trauma amongst drivers of light passenger vehicles by examining each of three critical components of the road trauma chain: exposure to risk, crash risk per unit exposure and injury outcome per crash event. Therefore it is useful to consider each specific analysis input as well as how the specific form of each relates to the analysis outcome.

First, the BTRE estimates of future heavy vehicle travel used in this study are the nationally recognised government estimates of past and predicted future heavy vehicle travel and hence appeared the best estimates for use in this study. However many unexpected things can alter demand for travel and any error in predicted heavy vehicle travel trends will translate proportionately to error in the estimates of future road trauma. Second, the estimates of crash risk per heavy vehicle kilometre travelled have been calculated using New South Wales crash data inflated to national values. The use of New South Wales data was necessary as it was the only state database with consistent and reliable reporting of tow-away and higher severity crashes where truck involved crashes are identified explicitly in the database. A key assumption of this approach is that crash trends in New South Wales are representative of the national average and will remain so in the future in both relative and proportionate terms.

The above two inputs combine to generate estimated crash rates. The influence of crash rates on predicted levels of heavy vehicle road trauma is evident in the diverging estimates presented under the two crash rate scenarios. This illustrates the importance of the input variables and the interactions between them in determining the predicted level of heavy

vehicle related road trauma. Therefore, in considering the scenario that is likely to most accurately represent future outcomes the reliability of the input variables is relevant.

The final critical input to the model of heavy vehicle related road trauma is the estimated crashworthiness of the light vehicle fleet by market group as a function of the heavy vehicle collision partner. The estimates used in the model, whilst labelled crashworthiness, are a function both of the crashworthiness of the light passenger vehicle class and the aggressivity of each heavy vehicle class. The models predicting total road trauma have not accounted for change in either crashworthiness of the light vehicle fleet or aggressivity of heavy vehicles over time. Instead they have assumed crashworthiness and aggressivity remain static. It is also noted that the crashworthiness estimates used in the models developed here relate only to driver injury outcome.

This study has considered one scenario as a possible solution to predictions of increases in heavy related fatalities and serious injuries, namely the removal of articulated trucks from metropolitan areas. Regardless of the crash rate scenario applied, this potential solution does not result in a reduction of heavy vehicle related road trauma. Indeed, road trauma could be expected to increase were articulated trucks to be replaced with rigid trucks in metropolitan areas. The model developed in the study could be used to examine many other scenarios. The only real substitution in heavy vehicle composition that is practical, however, is the distribution between rigid and articulated trucks. As shown by the scenario considered, current practice within the constraints of practicality is probably not too far from the optimum. From the general results in the study, it would seem the most viable ways of reducing heavy vehicle related road trauma are to reduce either the heavy vehicle exposure, crash risk or both and to continue to improve light vehicle crashworthiness and reduce heavy vehicle aggressivity.

LIMITATIONS AND ASSUMPTIONS

The analysis undertaken in this study is subject to a number of assumptions and qualifications. Both of the scenarios of future crash rates estimate changes in heavy vehicle crash rates as a function of changes in heavy vehicle usage only. Changes in the usage of light passenger vehicles and the influence of such changes on heavy vehicle crash rates are not considered. Future work in this area would benefit from estimating future changes in light passenger vehicle travel, preferably by market group, and considering the combined influence of these changes and estimated changes in heavy vehicle travel on heavy vehicle crash rates for the three classes of heavy vehicle identified in this study. Second, the model considers the influence of heavy vehicle travel on light passenger vehicle drivers only. Consideration is not given to the influence of growth in heavy vehicle travel on other road users such as pedestrians, bicyclists, motorcyclists or heavy vehicle occupants themselves.

The final limitation to be noted related to the data used to estimate heavy vehicle crash rates. As stated previously, crash rates are estimated using national estimates of heavy vehicle exposure and NSW crash data scaled to represent the national situation using national fuel sales data. However, by scaling NSW crash data to represent the national situation and to calculate national crash rates, it is assumed that proportionate heavy vehicle exposure does not differ significantly across Australian States and Territories. The validity of this assumption has not been tested. An alternative to adopting this approach would be to obtain heavy vehicle exposure data for metropolitan and non-metropolitan areas of NSW and calculate crash rates for NSW only. National estimates of heavy vehicle

road trauma could then be estimated based on the assumption that national heavy vehicle crash rates mirror those experienced in NSW. The relative merit of this alternative approach should be considered in future work in this area.

1 INTRODUCTION AND AIMS

Increased travel by heavy vehicles has been identified as one of the key components of total growth in vehicle travel to 2010. Given the obvious incompatibility between heavy vehicles and the light passenger vehicle fleet in crash situations, the anticipated rise in heavy vehicle travel raises questions about the likely impact on road trauma levels should the anticipated increases be realised. Previous work in this area has examined average injury outcomes of light passenger vehicles in collisions with heavy vehicles (Newstead et al., 2004a). This work highlighted the differential aggressivity of three heavy vehicle types (articulated trucks, rigid trucks and buses) and the variation in the safety performance of different types of light passenger vehicles in collisions with these vehicles. In light of the differences in injury outcome by light passenger vehicle type and heavy vehicle collision partner, changes in average injury outcome across all crash types involving the light passenger vehicle fleet were examined having regard to projected increases in heavy vehicle travel.

Previous work has not, however, considered the influence of growth in heavy vehicle travel on total road trauma levels associated with these vehicles. The aim of this study was to examine the effect of anticipated growth in heavy vehicle travel on the light passenger vehicle fleet in terms of changes in total road trauma levels. It was anticipated that the analysis would provide the basis for understanding the relationship between the major variables contributing to heavy vehicle related road trauma. For the purposes of this study, road trauma levels are measured by the number of light vehicle driver fatalities and serious injuries resulting from light passenger vehicle collisions with heavy vehicles. The factors that likely influence these levels include: growth in heavy vehicle transport and the area of that growth (i.e. metropolitan or non-metropolitan), the relative seriousness of outcomes in light passenger vehicle collisions with the three heavy vehicle types, differences between crash outcomes in metropolitan and non-metropolitan areas and changes in heavy vehicle crash rates due to improved safety of both vehicle and non-vehicle infrastructure.

The remainder of the report details the process followed to measure the impact of these factors on road trauma levels associated with heavy vehicle travel. First, the data required to produce estimates of projected total road trauma resulting from collisions with heavy vehicles are presented. Second, historical trends in heavy vehicle travel and heavy vehicle crashes are reviewed to provide a base level of road trauma resulting from heavy vehicle travel. The calculation method is then presented followed by the results of the analysis. Finally, the key implications of the research are discussed.

2 DATA

For the purposes of this study heavy vehicles are defined in three classes: articulated trucks, rigid trucks and buses. The classifications chosen reflect the detail available in the supporting data available for analysis. There are three key data sources that contain information relevant to the nature and extent of travel undertaken by these vehicle types and the frequency of crashes in which they are involved.

First, the Bureau of Transport and Regional Economics (BTRE) provided MUARC with updated estimates of national vehicle kilometres travelled by commercial vehicles (including buses) first reported in BTRE (2002). This updated data has since been published in a BTRE report to the Australian Greenhouse Office, Department for the Environment and Heritage (BTRE, 2005). For the period 1990 to 2004, this included data

on total vehicle kilometres travelled for each of the three heavy vehicle types in both metropolitan and non-metropolitan areas. For the period 2005 to 2020 forecasts of travel by each of the heavy vehicles types produced by the BTRE were provided both in aggregate and according to the area of travel (i.e. metropolitan vs. non-metropolitan travel). Details of the forecasting methods and changes to estimated growth in total annual vehicle kilometres are provided in BTRE (2002) and BTRE (2005).

The second key data source was the Australian Bureau of Statistics (ABS) Surveys of Motor Vehicle Use. This survey provided data relating to the extent of travel undertaken by both articulated and rigid trucks for the years 1998 to 2003. In particular the following variables were relevant to this study:

- average annual vehicle kilometres travelled by vehicle type
- average annual tonne kilometres by vehicle type

NSW Police reported crash data covering those crashes resulting in death, injury or a vehicle being towed away during the period 1990 to 2003 is used in conjunction with vehicle information supplied by NSW RTA to provide information concerning the frequency of collisions involving articulated trucks, rigid trucks or buses. The data also provides information relating to the distribution of heavy vehicle crashes by the opposing light passenger vehicle market group. Full details of the data used are provided in Newstead et al (2005).

The NSW crash and vehicle data described above was also used to generate another primary input of this study. The data was used in associated work to produce revised estimates of the aggressivity of heavy vehicles towards light passenger vehicles categorised into distinct market groups. These aggressivity estimates measure the risk of death or serious injury to a driver of a light passenger vehicle from a given market group when colliding with a given heavy vehicle type. These estimates were produced for all crashes, for crashes occurring in metropolitan areas only and for crashes occurring in non-metropolitan areas only. Full details of the estimates and associated methodology are provided in Appendix B.

Finally, monthly distillate fuel sales data for the period 1991 to 2004 provided for each State and Territory by the Federal Department of Industry, Science and Resources was used to scale NSW crash data to generate estimates of national heavy vehicle crashes. The issues surrounding the use of scaled NSW crash data to represent national heavy vehicle crashes and the associated impact on heavy vehicle crash rates is discussed in Section 6.1.

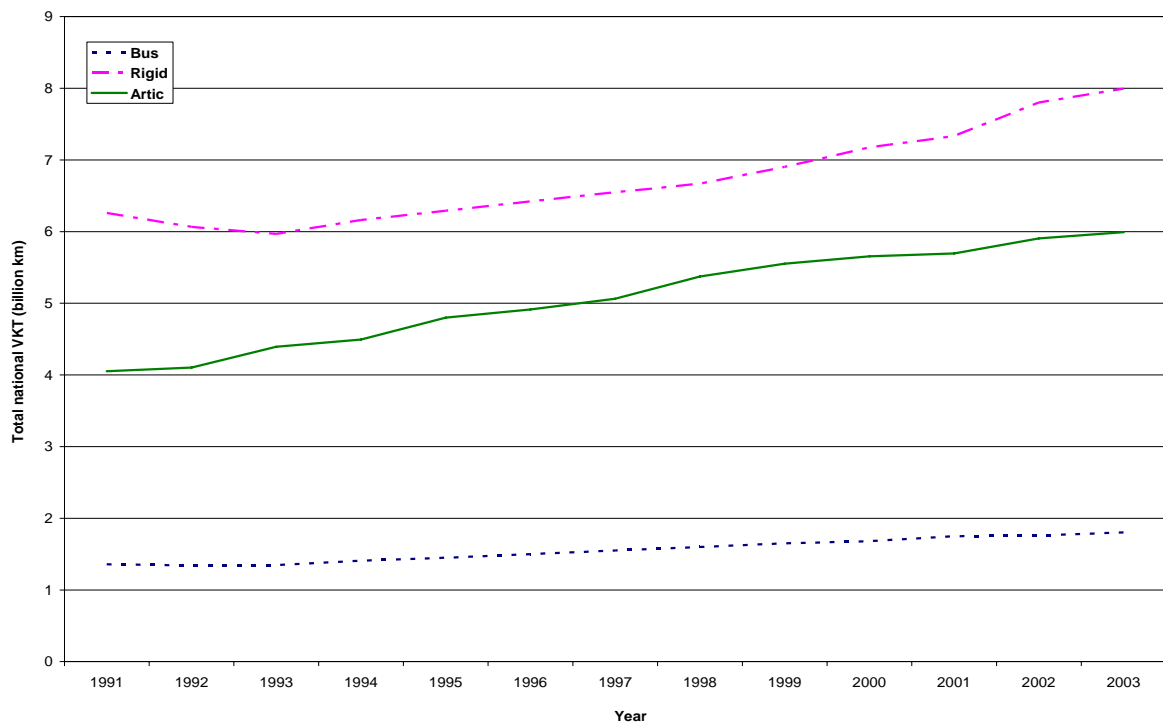
3 ANALYSIS INPUT MEASURES

3.1 HISTORICAL TRENDS IN HEAVY VEHICLE TRAVEL AND CRASHES

In assessing potential future changes in heavy vehicle travel and heavy vehicle crashes and their likely impact on road trauma, the first step is to examine historical trends in both these measures. The series of charts that follow investigate both heavy vehicle exposure and heavy vehicle crash rates over the period 1991 to 2003.

Using the updated estimates of national, annual vehicle kilometres travelled by heavy vehicles supplied by the BTRE, Figure 1 below plots total national vehicle kilometres travelled over the period 1991 to 2003.

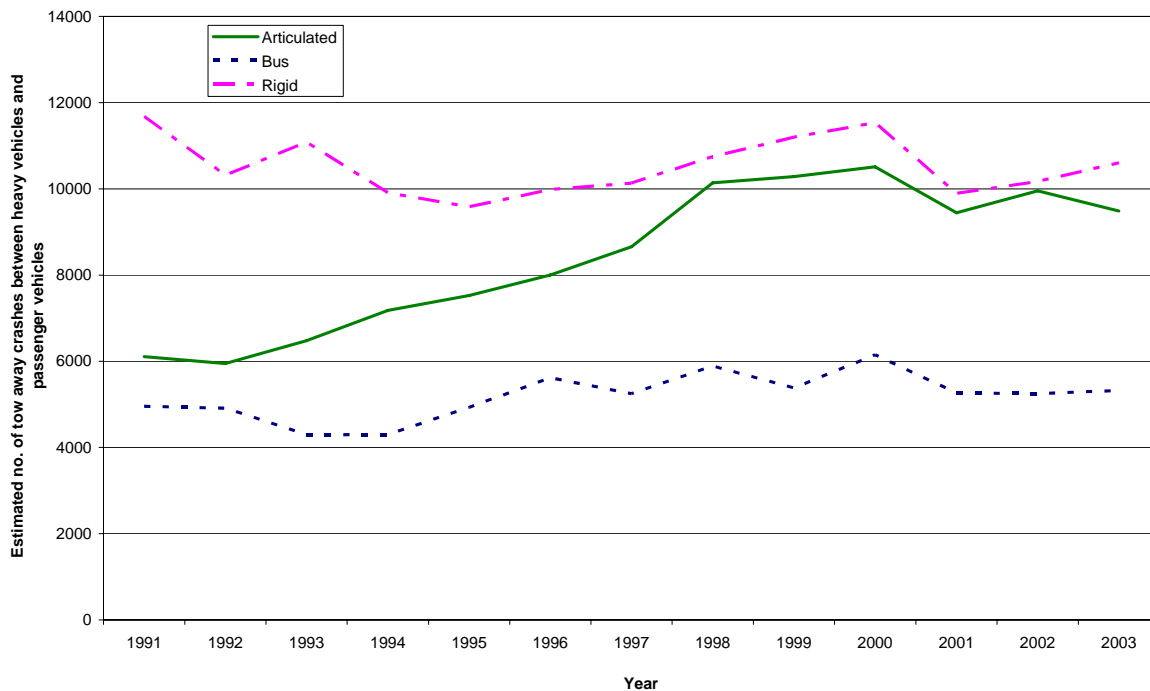
Figure 1. Total national vehicle kilometres travelled (billion km)



It is evident that, in the early 1990s, there was a period of decline in total annual travel by both rigid trucks and buses, most likely associated with the economic recession at the time. At the same time, travel by articulated trucks remained stable. Over the next decade, travel across all heavy vehicle classes increased steadily although the rate of growth varied across vehicle types. This upward trend in heavy vehicle travel represents an increase in exposure to crash risk. Therefore, it is useful to examine changes in the total number of crashes occurring over the corresponding period to determine what change, if any, has occurred in the level of risk associated with each million vehicle kilometres travelled.

Figure 2 plots the estimated number of crashes between heavy vehicles and light vehicles occurring nationally over the period 1991 to 2003. The data present is derived from NSW Police reported crash data and scaled to represent the national situation. Crash data from New South Wales is the most useful for this analysis as it classifies heavy vehicles into the categories of interest in this study and also provides a consistent time series of data on both injury and non-injury crashes over an extended time period. The process of scaling the New South Wales data to represent national figures is described in section 4.1. It assumes that heavy vehicle crash rates do not differ significantly across Australian States and Territories.

Figure 2. Estimated national number of tow away crashes between heavy vehicles and passenger vehicles.



There is broad correspondence between growth in heavy vehicle travel and the number of heavy vehicle crashes over the period examined. The noted decline in rigid truck and bus travel and stable levels of articulated truck travel in the early 1990s was associated with a decline in the number of crashes involving each of these heavy vehicle types. Similarly, articulated trucks and buses experience a rise in the number of crashes as travel increases. However, the number of crashes involving rigid trucks does not increase significantly as travel by that vehicle type increases. To confirm the extent of the association between vehicle kilometres travelled and the number of crashes, Figure 3 shows the heavy vehicle crash rate per million vehicle kilometres travelled.

It is noted that, in calculating national heavy vehicle crash rates a combination of NSW crash data (scaled to represent the national situation) and national exposure data is used. This assumes that proportional heavy vehicle exposure does not differ significantly across Australian States and Territories. Cosgrove (2003) exposure estimates indicate substantial differences between NSW and national exposure trends in non-metropolitan areas, especially for rigid trucks. This brings into question the validity of the assumption made in this study for non-metropolitan areas. An alternative approach would be to use NSW data only to estimate crash rates and assume that national crash rates mirrored those in NSW. Although, the scope of this project did not extend to investigating this alternative approach, future work in this area would benefit from its consideration.

Figure 3. Estimated heavy vehicle crash rate per million vehicle kilometres travelled across all road types (multiple vehicle tow-away crashes).

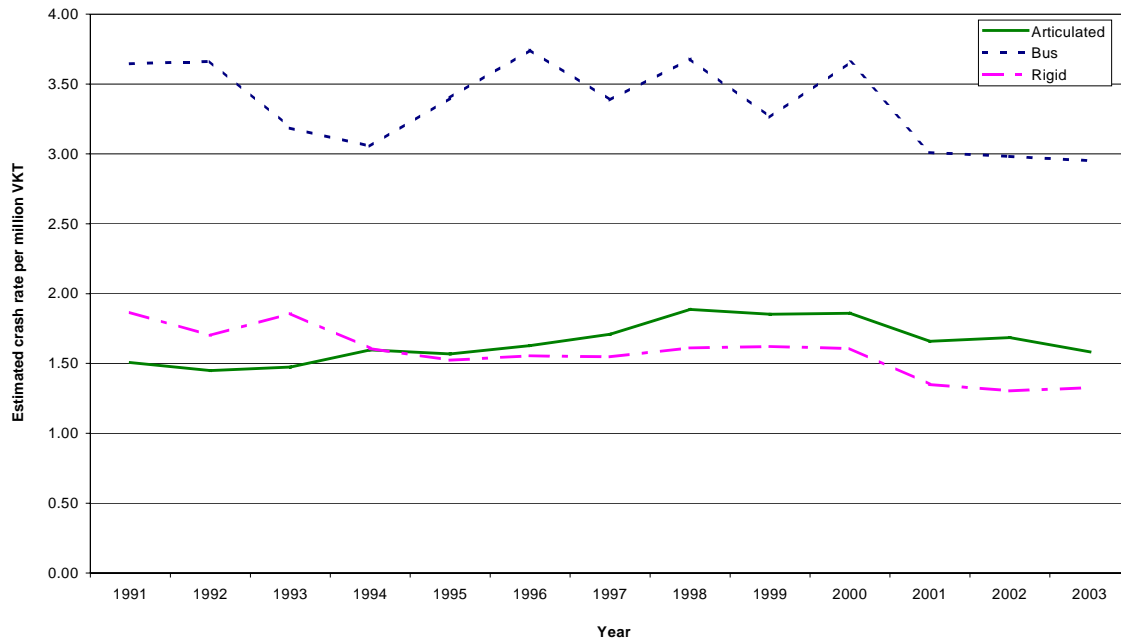


Figure 3 shows a clear difference in the risk of involvement in a tow-away crash for the three heavy vehicle types. Buses experience the highest levels of crash risk followed by articulated trucks and rigid trucks. However, the crash rate associated with buses and rigid trucks has decreased over time whilst the articulated truck crash rate has risen slightly. These differences in crash risk will influence the impact of future growth in heavy vehicle travel on road trauma levels particularly if travel by different modes of heavy vehicle transport grows at varying rates. This influence will be considered following the estimation of changes in total road trauma levels resulting from future increases in heavy vehicle travel.

A further influencing factor on the impact of future growth in heavy vehicle travel is the distribution of that travel across metropolitan and non-metropolitan regions and the variation in crash rates across the two regions. Heavy vehicle crash rates have been calculated separately for metropolitan and non-metropolitan regions using travel and crash data identifying the region of travel. The following two charts plot the crash rate per million vehicle kilometres travelled for each of the heavy vehicle types in metropolitan and non-metropolitan areas respectively.

Figure 4. Estimated heavy vehicle crash rate per million vehicle kilometres travelled in metropolitan areas (multiple vehicle tow-away crashes).

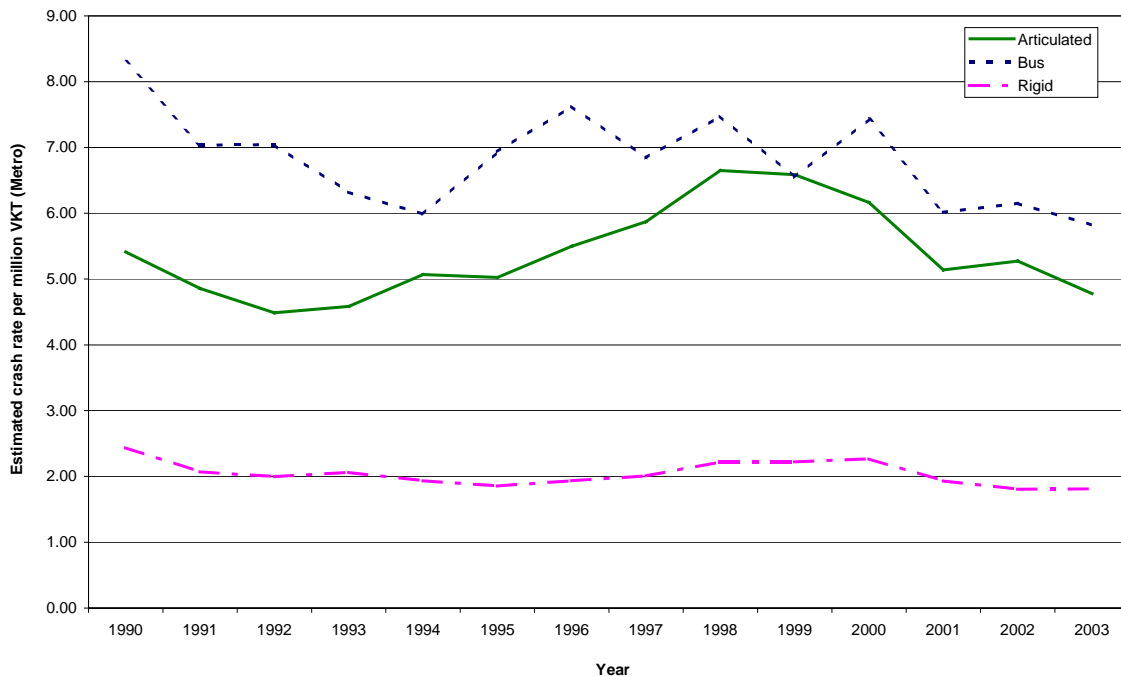
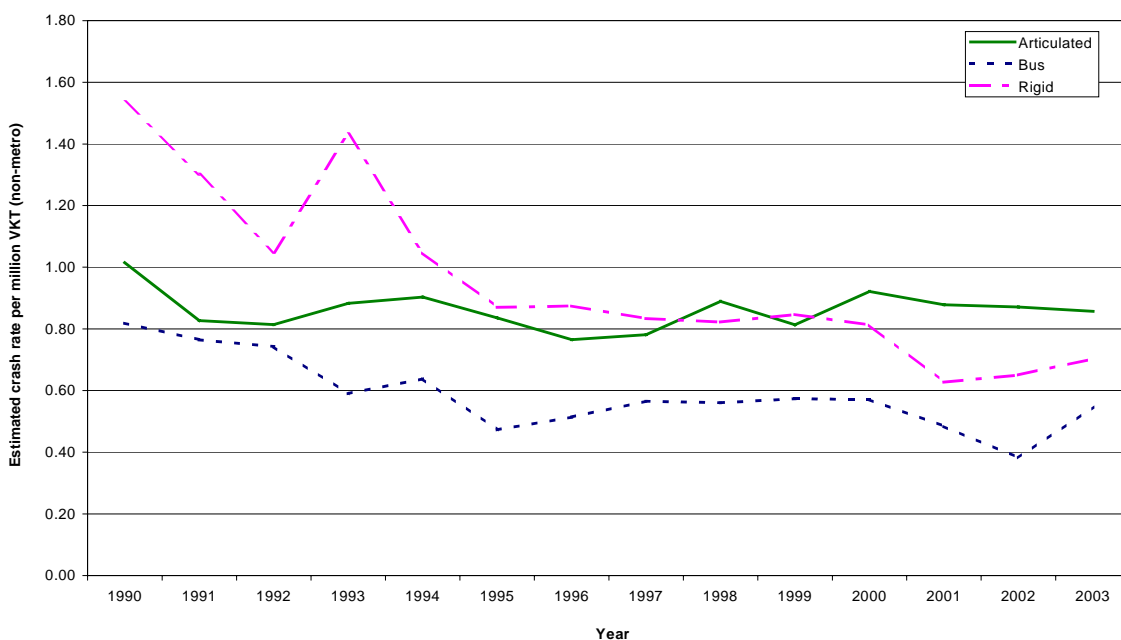


Figure 5. Estimated heavy vehicle crash rate per million vehicle kilometres travelled in non-metropolitan areas (multiple vehicle tow-away crashes).



It is evident that, across all three heavy vehicle types, crash rates per million vehicle kilometres travelled within metropolitan areas are substantially higher than in non-metropolitan areas. However, there is also a considerable difference in the relationship and time trends between metropolitan and non-metropolitan crash rates for each of the three heavy vehicle types. For example, the rigid truck crash rate has almost halved in non-metropolitan areas over the 14 year period whilst showing only a modest decrease in metropolitan areas. Similarly, crash rates for articulated trucks have varied only slightly in

non-metropolitan areas and experienced periods of significant growth and then decline over the same period in metropolitan areas. Examining the data in terms of the differences between rigid trucks and articulated trucks, there are noticeable differences in the crash rates of these two heavy vehicle types over time in both metropolitan and non-metropolitan areas. The reasons for these differences are not immediately clear and future work in this area is required to determine whether they are genuine or reflect in part some of the limitations of the data sources.

To further quantify the variation between metropolitan and non-metropolitan crash rates and begin to examine how this variation may influence the impact of future heavy vehicle travel on total road trauma levels, Table 1 below presents average metropolitan and non-metropolitan crash rates for the period 1998 to 2003 for articulated trucks, buses and rigid trucks respectively.

Table 1. Average heavy vehicle crash rates per million vehicle kilometres travelled in metropolitan and non-metropolitan areas (1998-2003)

Heavy Vehicle Type	Metropolitan Crash Rate (a)	Non-metropolitan Crash Rate (b)	Relative Difference (a)/(b)
Articulated Trucks	5.76	0.87	6.62
Buses	6.57	0.52	12.63
Rigid Trucks	2.04	0.74	2.76

It is evident that the greatest disparity between metropolitan and non-metropolitan crash rates exists for buses, followed by articulated trucks and rigid trucks. Buses have the highest crash rate in metropolitan areas followed by articulated trucks and rigid trucks. In contrast, in non-metropolitan areas articulated trucks experience the highest estimated crash rates followed by rigid trucks and buses. As these crash rates refer to collisions with light passenger vehicles only, potential explanations for the variations in the crash rates include differences in exposure to the light passenger vehicle fleet. Whilst this and other causes are not considered in detail in this study, investigation of these issues may act to validate the estimated heavy vehicle crash rates. An additional point of interest is that rigid trucks have a much lower crash rate than articulated trucks in metropolitan but not in non-metropolitan areas. Again, investigation of the potential causes of these differences such as the type of crashes in which the two heavy vehicles are involved, may act to validate the estimated heavy vehicle crash rates.

The differences in heavy vehicle crash rates become relevant later when examining possible restrictions on the area of heavy vehicle travel to reduce the impact of increased heavy vehicle travel on total road trauma levels.

3.2 CRASHWORTHINESS OF LIGHT PASSENGER VEHICLES IN COLLISIONS WITH HEAVY VEHICLES

A further influence on the impact of the growth in heavy vehicle travel on road trauma in the light passenger vehicle fleet is the risk of death or serious injury to light passenger vehicle drivers when colliding with heavy vehicles. Growth in travel by a heavy vehicle type that poses a comparatively high risk of injury to a light passenger vehicle driver may

be of more concern than growth in travel by a heavy vehicle type that poses a comparatively low risk of injury to a light passenger vehicle driver.

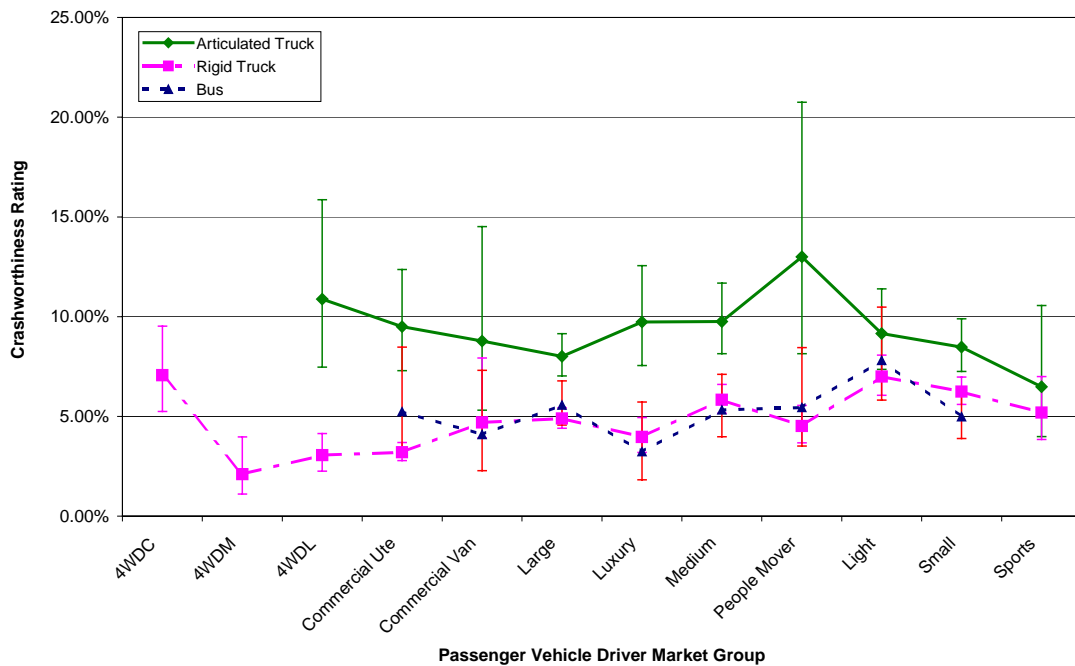
Crashworthiness of light passenger vehicles in collisions with heavy vehicles by light market group and heavy vehicle class have been estimated by Newstead et al (2004a) using crash data to the end of 2002. The light passenger vehicles were classified into one of 8 different market groups whilst the heavy vehicle collision partners were classified into the same three market groups considered in this study. In order to base this study on the most accurate and up to date crashworthiness estimates, the light passenger to heavy vehicle crashworthiness ratings of Newstead et al (2004a) have been updated for this study based on police reported crash data to the end of 2003 from Victoria, New South Wales, Western Australia, Queensland and New Zealand. The same methods detailed in Newstead et al (2004a) have been used to estimate the updated ratings. In contrast to the earlier ratings, the updated ratings presented here classify light passenger vehicles into one of 12 different market groups as used in estimating the Used Car Safety Ratings of Newstead et al (2005). Full details of the updated ratings are given in Appendix B and are summarised here.

The light vehicle market groups considered are:

Compact 4WD (4WDC)	Light
Medium 4WD (4WDM)	Small
Large 4WD (4WDL)	Medium
Commercial Utility	Large
Commercial Van	Luxury
People Mover	Sports

Figure 6 shows the estimated crashworthiness rating of light vehicles by market groups in collisions with each of the heavy vehicle types. The crashworthiness estimate represents the risk of death or serious injury to the light passenger vehicle driver in a collision with the given heavy vehicle type. 95% confidence limits are also given on each rating. Ratings were not estimated for some combinations due to insufficient crash data.

Figure 6. Crashworthiness by light passenger vehicle market group and heavy vehicle collision partner.



The risk to light passenger vehicle drivers differs by both light passenger vehicle market groups and the type of heavy vehicle involved. Articulated trucks, pose the greatest risk of death or serious injury to drivers of all light passenger vehicle types for which estimates could be obtained. However, for crashes involving articulated trucks, statistically significant differences in the risk to drivers of the various light passenger vehicle market groups could not be identified. It is noted that, as far as possible, these estimates of crashworthiness have been adjusted for factors other than vehicle type that may influence injury outcome. These factors include the speed zone of the crash location which is intended to act as a proxy for the crash location (metropolitan/non-metropolitan). Therefore, to the extent that the speed zone of the crash location acts as a proxy for crash location and the adjustment process is effective, it is unlikely that the higher severity associated with collisions between articulated trucks and light passenger vehicles is attributable to differences in crash location between articulated trucks and other heavy vehicle types. Unfortunately, given the smaller amounts of data available separately for metropolitan and non-metropolitan crashes only, it is not possible to identify whether crashes between articulated trucks and light passenger vehicles are more severe than other heavy vehicle to light passenger vehicle crashes in both metropolitan and non-metropolitan areas (see Figures 7 and 8).

Drivers of light passenger vehicles colliding with rigid trucks and buses experience a similar rate of death and serious injury, however, the risk does appear to differ according to the market group of the light passenger vehicle. At particular risk are drivers of compact 4WDs, light passenger cars and small passenger cars. At significantly lower risk in collisions with rigid trucks are drivers of medium or large 4WDs and commercial utilities.

The crashworthiness of light passenger vehicles by market group in collisions with heavy vehicles has also been estimated separately for metropolitan and non-metropolitan areas. Figures 7 and 8 below present the results graphically whilst full details of the calculations also appear in Appendix B.

Figure 7. Crashworthiness by light passenger vehicle market group and heavy vehicle collision partner: metropolitan areas.

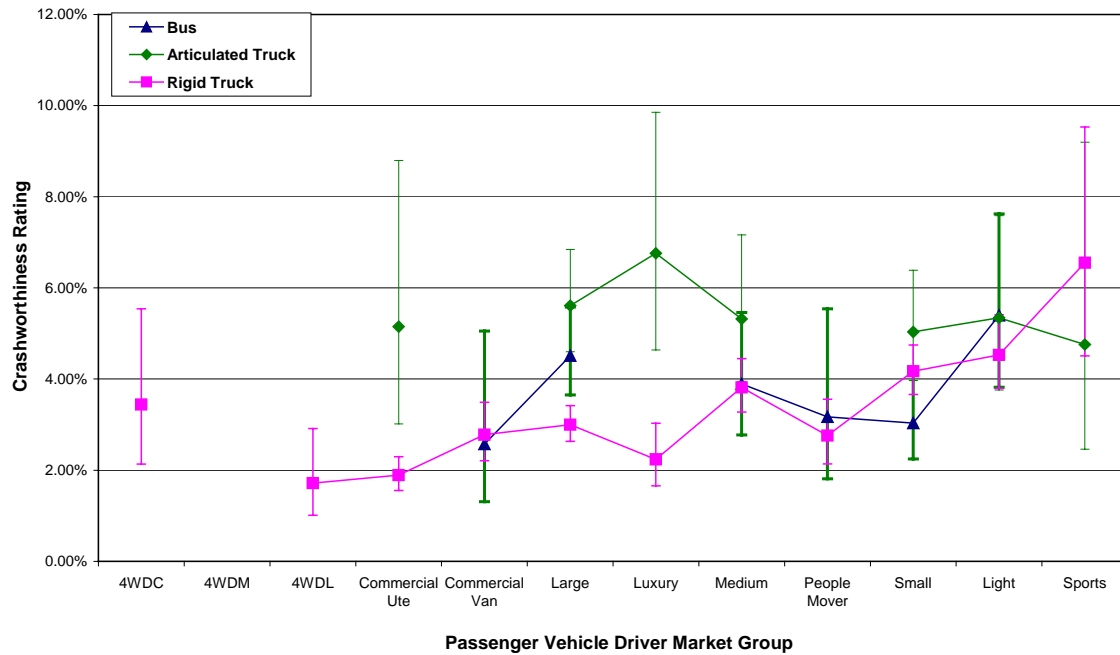
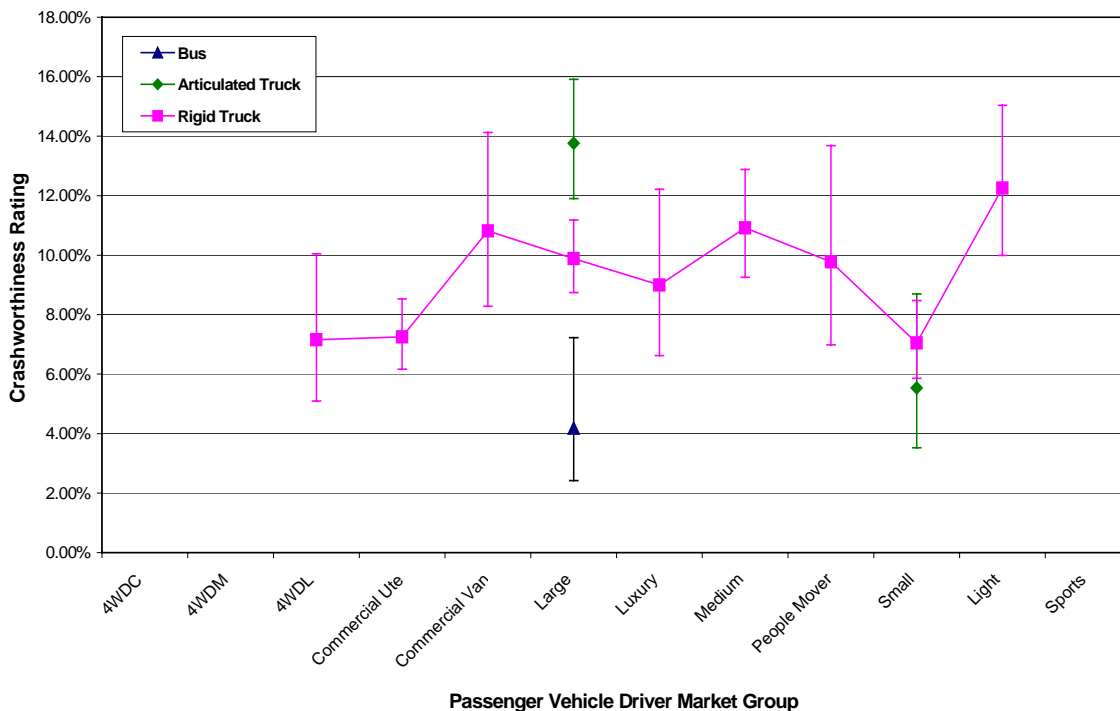


Figure 8. Crashworthiness by light passenger vehicle market group and heavy vehicle collision partner: non-metropolitan areas.



It was not possible to estimate crashworthiness estimates for all light passenger vehicle market groups separately for metropolitan and non-metropolitan areas given the smaller amounts of data available. Nevertheless, where estimates are available, heavy vehicle collisions occurring in non-metropolitan areas are associated with poorer safety performance by light passenger vehicles regardless of the heavy vehicle type involved.

Despite the difference in risk posed by the three heavy vehicle types, when examining the impact on total road trauma levels, the influence of the crashworthiness of light passenger

vehicles in collisions with heavy vehicles must not be considered in isolation from the associated crash rates. This ensures that the risk of death or serious injury to a light passenger vehicle driver in a tow-away crash with a heavy vehicle is appropriately weighted by the likelihood of a tow-away crash with that heavy vehicle type occurring. This issue is discussed further in the description of the analysis method that follows.

4 METHOD FOR PREDICTING HEAVY VEHICLE RELATED ROAD TRAUMA

4.1 BASE LEVEL OF ROAD TRAUMA

As stated previously, the aim of this study was to examine the effect of anticipated growth in heavy vehicle travel on total road trauma levels in the light passenger vehicle fleet. In the first instance, this required the determination of a base level of road trauma related to heavy vehicle travel. This was achieved in three stages, each of which was applied to data for the years 1998 to 2003. The same approach was also adopted to estimate future road trauma levels in metropolitan and non-metropolitan areas respectively using data specific to these areas.

Stage One: *Estimate the total national number of crashes involving each type of heavy vehicle according to Equation 1.*

$\text{No. of national heavy vehicle crashes}_j = \text{NSW heavy vehicle crashes}_j / 0.292 \quad \dots \text{Eqn 1.}$

where j is the heavy vehicle type.

As national data on the number of tow-away heavy vehicle crashes is not available it was necessary to estimate total heavy vehicle tow-away crashes. NSW Police reported crash data, merged with vehicle identification data, contained the total number of tow-away crashes involving heavy vehicles occurring in NSW for the relevant years. This data was scaled to estimate the number of national heavy vehicle crashes using national distillate fuel sales data supplied by the Department of Industry, Science and Resources for 1991 to 2004. These data were used as a proxy for vehicle travel to determine the average proportion of national travel represented by NSW (29.2%). The NSW crash numbers were adjusted upwards using this proportion to provide estimates of the number of national tow-away crashes occurring in the relevant years according to Equation 1. In adopting this approach it was assumed that proportionate heavy vehicle exposure does not differ significantly across Australian States and Territories.

Stage Two: *Determine the distribution of each type of heavy vehicle crash by the light passenger vehicle collision partner and estimate the number of light vehicle driver casualties involved in each collision type.*

To measure total road trauma levels associated with heavy vehicle travel, estimates of light passenger vehicle crashworthiness by heavy vehicle type and light passenger vehicle market group were applied to the number of heavy vehicle crashes occurring between each combination of heavy vehicle and light passenger vehicle market group. This enabled variation in injury outcome by light passenger vehicle market group and heavy vehicle collisions partner to be appropriately reflected in forecasts of total road trauma associated with heavy vehicle travel. In particular, the estimates of vehicle crashworthiness were

adjusted as far as possible for factors other than vehicle type that may influence injury outcome. Therefore, using these estimates of crashworthiness rather than raw injury data ensured that the estimated changes to total road trauma reflected only the vehicles involved in the collisions and not the drivers or specific crash circumstances. However, adopting this approach required knowledge of the proportion of all crashes occurring in each configuration. For example, what proportion of the 10,144 articulated truck crashes occurring in 1998 involved small vehicles, large 4WDs or medium sized vehicles? Average proportions for each vehicle to heavy vehicle configuration for the period 1998 to 2003 were derived from NSW heavy vehicle crash data detailed in Section 2 and Newstead et al (2005) again assuming these represented the national situation. These proportions were then multiplied by the total number of crashes involving the relevant heavy vehicle type to estimate the number of drivers involved in each collision type in each year.

Stage Three: *Using the estimates of crashworthiness by heavy vehicle and driver market group provided in Appendix B for each crash configuration, calculate the estimated number of fatalities and serious injuries resulting from heavy vehicle crashes.*

Step two above estimated the number of drivers involved in each collision type in a given year. Equation 2 below calculates the number of fatalities and serious injuries resulting from these crash involvements

$\text{No. of fatalities and serious injuries}_i = CWR_i \times \text{No. of involved drivers}_i \quad \dots \text{Eqn 2.}$

where *i* is the crash configuration.

Where crashworthiness estimates were not able to be estimated due to insufficient data, raw data on the number of fatalities and serious injuries per 100 crash involvements were used as a proxy for crashworthiness.

4.2 FORECASTING LEVELS OF ROAD TRAUMA

To determine the impact of future heavy vehicle growth on total road trauma levels it was necessary to forecast road trauma levels associated with each heavy vehicle type into the future. Using the method described in Section 4.1 requires forecasts of the number of crashes involving each of the three heavy vehicle types. BTRE data provided forecasts of increases in heavy vehicle travel but not heavy vehicle crashes. However, given travel and crash data from previous years it was possible to calculate annual heavy vehicle crash rates and apply these to forecasted travel to estimate the number of future crashes involving each heavy vehicle type.

The crash rate per million vehicle kilometres travelled for each year between 1998 and 2003 was calculated according to Equation 3.

$\text{Crash rate}_j (\text{per million vkt}) = \text{No. of national heavy vehicle crashes}_j \div \text{Million vkt}_j \quad \dots \text{Eqn 3.}$

where *j* is the heavy vehicle type.

Equation 3 was used to calculate an individual crash rate for each year of the period 1998 to 2003. In applying a crash rate to future heavy vehicle travel a decision was required about which crash rate to use. In this report two alternatives are presented. The first uses

crash rates for the period 1998 to 2003 to forecast crash rates for 2004 to 2010 using a linear trend. The second assumes that the crash rate remains stable at the 2003 levels over the period 2004 to 2010. The values of the forecasted crash rates are shown in Appendix A.

Two alternative forecasts of heavy vehicle crash number were computed by multiplying the crash rate by forecast vehicle kilometres travelled. Having estimated the number of each heavy vehicle crash type for 2004 to 2010, steps two and three detailed above were applied to each of the years in the forecast period. The same approach was also adopted to estimate future road trauma levels in metropolitan and non-metropolitan areas respectively using data specific to these areas. The estimates specific to metropolitan and non-metropolitan areas are generated independently of the analysis of all areas and when combined may not precisely sum to the estimates generated for all areas due to estimation error.

4.3 SCENARIOS OF DIFFERENT MIX IN TRUCK TRAVEL

Given the particularly high crash rates associated with articulated truck travel in metropolitan areas and the potential for growth in travel by these vehicles to result in large increases in road trauma, a further forecast scenario was examined. Under this scenario, all articulated truck travel in metropolitan areas was removed and the load transferred to rigid trucks. No change was made to the operating environment in non-metropolitan areas.

It is clear that more rigid trucks than articulated trucks would be required to carry the same load. Therefore, the number of rigid trucks replacing articulated trucks in metropolitan areas had to be adjusted upwards. The ABS survey of motor vehicle use provided average tonne kilometres travelled and average kilometres travelled by articulated and rigid trucks. From this the average load of rigid and articulated trucks was calculated and an average taken for the period 1998 to 2003. On average, a single articulated truck carries 4.76 times more than a single rigid truck. Therefore, for each articulated truck removed from metropolitan areas, 4.76 rigid trucks were introduced to replace them under the considered scenario.

After adjusting the vehicle kilometres travelled and the distribution of heavy vehicle crash configurations in metropolitan areas appropriately, the calculation of total road trauma was completed in the same manner as described in 4.1 and 4.2.

5 RESULTS

5.1 FORECAST HEAVY VEHICLE TRAVEL

Data from the BTRE was used to provide information on the forecast level of vehicle travel for the period 2004 to 2010. The charts that follow show estimated levels of future vehicle kilometres travelled by each of the three heavy vehicle crash types across all areas and in metropolitan areas and non-metropolitan areas separately. Historical data from 1998 to 2003 is included in each of the charts to provide some context for the forecasts.

Figure 9. BTRE National forecast of billion vehicle kilometres travelled (2004-2010) by heavy vehicles.

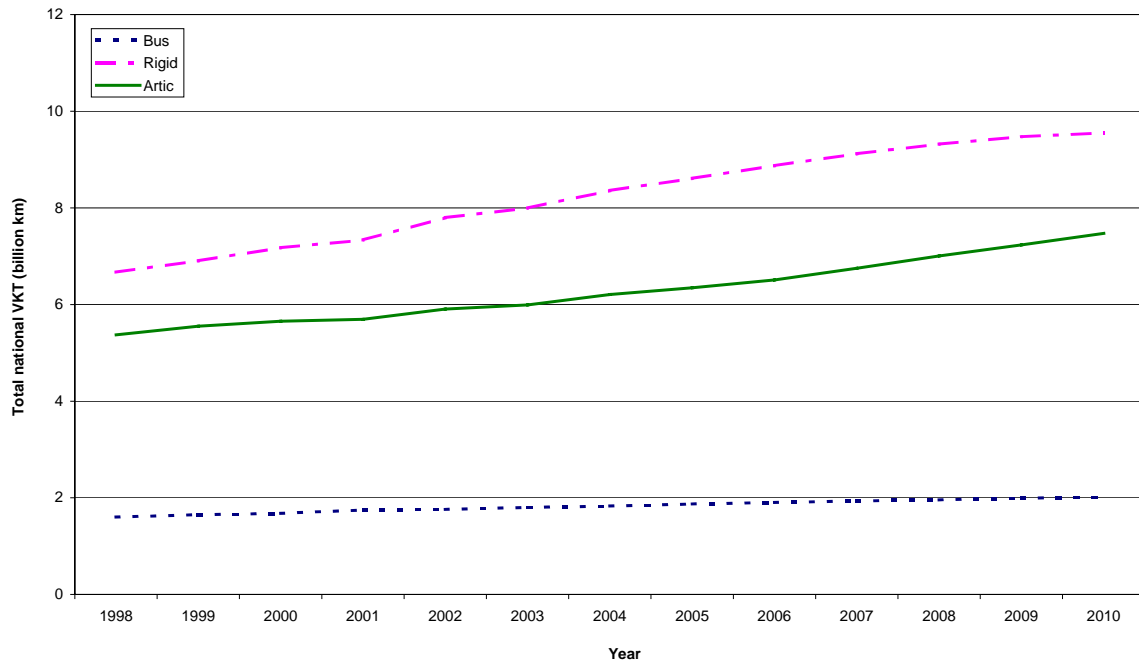


Figure 10. BTRE National forecast of billion vehicle kilometres travelled (2004-2010) by heavy vehicles: Metropolitan areas.

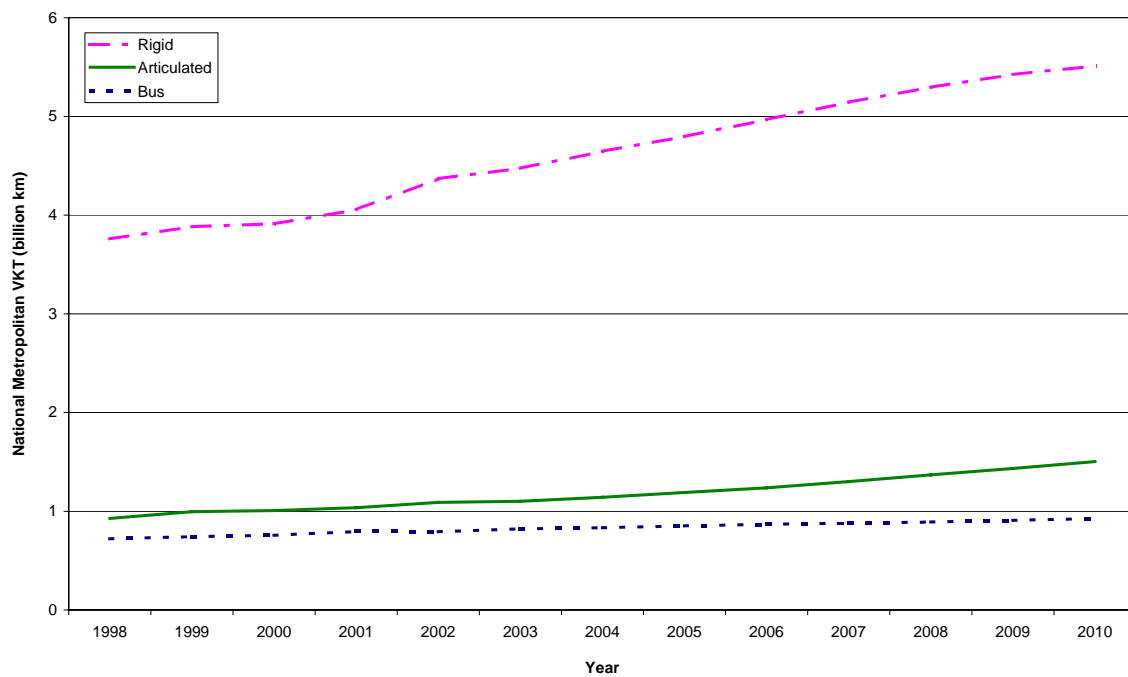
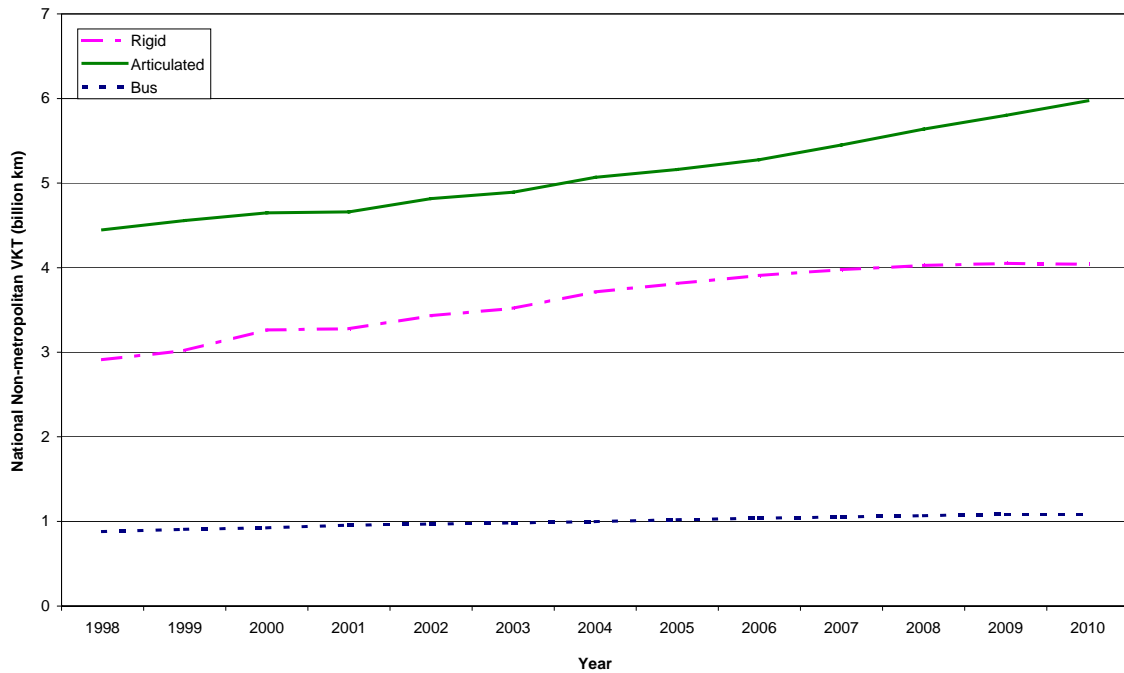


Figure 11. BTRE National forecast of billion vehicle kilometres travelled (2004-2010) by heavy vehicles: Non-metropolitan areas.



From the three charts above it is evident that there is expected to be substantial growth in both rigid truck and articulated travel and modest growth in bus travel over the forecast period. Rigid trucks are expected to continue to travel the most with the majority of travel completed in metropolitan areas. Further, growth in rigid truck travel is expected to be greatest in metropolitan areas. In contrast, articulated truck travel is predicted to increase most in non-metropolitan areas.

5.2 FORECAST ROAD TRAUMA LEVELS

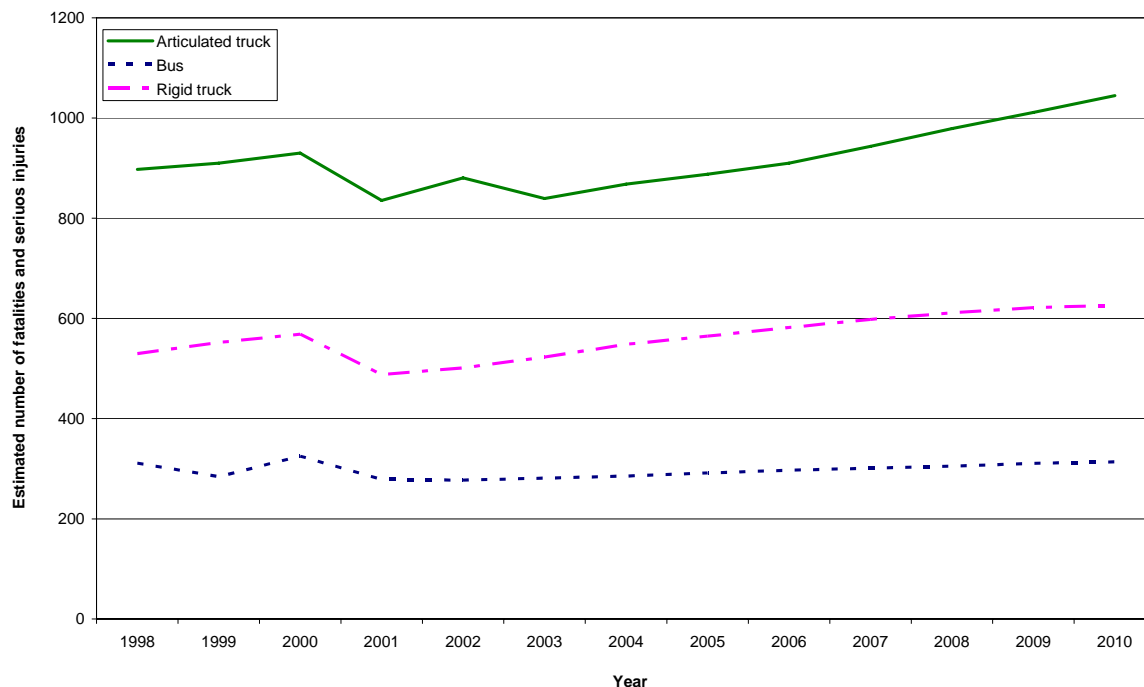
Section 4.2 details the two scenarios for forecasting future road trauma levels that have been investigated. The first applies the 2003 crash rate to future years whilst the second assumes a linear trend in crash rates over the forecast period. The resulting estimates of road trauma differ according to the crash rates applied and when viewed together provide a range of potential future road trauma levels.

The following series of charts present the estimated national number of fatalities and serious injuries resulting from collisions between heavy vehicles and light passenger vehicles between 1998 and 2010.

5.2.1 Combined Metropolitan and Non-Metropolitan Areas

Figures 12 and 13 show estimated road trauma levels across both metropolitan and non-metropolitan areas.

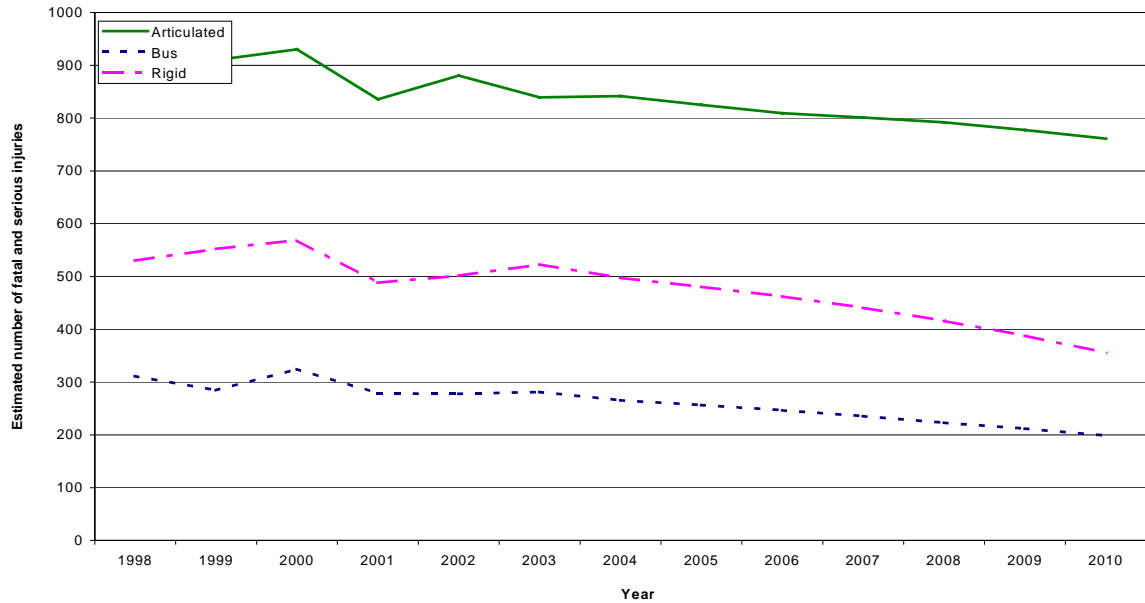
Figure 12. Estimated number of fatalities and serious injuries resulting from collisions between heavy vehicles and light passenger vehicles: 2003 crash rate maintained.



When assuming stable crash rates from 2003 onwards, there is evidence of substantial increases in the number of fatal and serious injuries resulting from light passenger vehicle collisions with each heavy vehicle type. The greatest increase is generated by articulated truck travel. Although rigid trucks are forecast to travel more vehicle kilometres over the forecast period and the crash rates of the two vehicle types do not differ greatly, the severity of crashes involving articulated trucks is approximately twice that of crashes involving rigid trucks. Therefore, the higher severity associated with articulated truck crashes appears to be the primary contributor to the higher number of fatalities and serious injuries associated with articulated truck travel. However, it is also noted that forecast percentage growth in vehicle travel is greater for articulated trucks than rigid trucks particularly in non-metropolitan areas.

Under the alternative scenario, where crash rates for the three heavy vehicle types decline according to a linear trend over the forecast period, the number of fatal and serious injuries resulting from light passenger vehicle collisions with each heavy vehicle type declines slowly over the forecast period. The predicted road trauma trends for crashes involving each heavy vehicle class are shown in Figure 13. Under this scenario, increases in heavy vehicle travel are more than offset by declining crash rates and the number of fatal and serious injuries resulting from collisions with heavy vehicles will decrease over time despite increases in vehicle kilometres travelled.

Figure 13. Estimated number of fatalities and serious injuries resulting from collisions between heavy vehicles and light passenger vehicles: Linear forecast of crash rates.



5.2.2 Metropolitan Areas

Figures 14 and 15 show estimated road trauma levels for metropolitan areas under the two scenarios of projected crash risk considered. As for the overall projections, the level of road trauma predicted differs significantly between the two scenarios. Figure 14, using 2003 crash rates in the forecast, predicts a steady increase in the number of fatalities and serious injuries resulting from light passenger vehicle collisions with all heavy vehicle crash types. Like the combined analysis, articulated trucks generate the highest number of injuries and buses the lowest. In addition, the rate of growth of fatalities and serious injuries appears to be greatest for articulated trucks.

Figure 14. Estimated number of fatalities and serious injuries resulting from collisions between heavy vehicles and light passenger vehicles in metropolitan areas: 2003 crash rates maintained.



Under the alternative scenario in Figure 15, where extrapolated crash rates from past trends are used, estimates of road trauma attributable to all heavy vehicle crash types are dramatically lower. This is particularly so for articulated truck crashes. This appears to be primarily a result of the sharp decline in crash rates predicted over this period. As stated in Section 4.2, crash rates are predicted on the basis of a linear trend. Sustained trends to improved heavy vehicle crash rates would be required for these estimated reductions in road trauma to be realised.

Figure 15. Estimated number of fatalities and serious injuries resulting from collisions between heavy vehicles and light passenger vehicles in metropolitan areas: Linear forecast of crash rates.



5.2.3 Non-metropolitan Areas

Unlike in metropolitan areas, the two scenarios considered for non-metropolitan areas produce less diverse forecasts of heavy vehicle related road trauma particularly for road trauma related to articulated truck travel (Figures 16 and 17). This is primarily due to the predicted stability of crash rates for articulated trucks in non-metropolitan areas and the consequent consistency between the 2003 articulated truck crash rate and articulated truck crash rates predicted using a linear forecast. Similarly, the divergence between estimated levels of fatalities and serious injuries resulting from rigid truck and bus travel under the two scenarios results from the difference between the 2003 rigid truck and bus crash rates and the same crash rates forecast for the period 2004 to 2010.

Figure 16. Estimated number of fatalities and serious injuries resulting from collisions between heavy vehicles and light passenger vehicles in non-metropolitan areas: 2003 crash rates maintained.

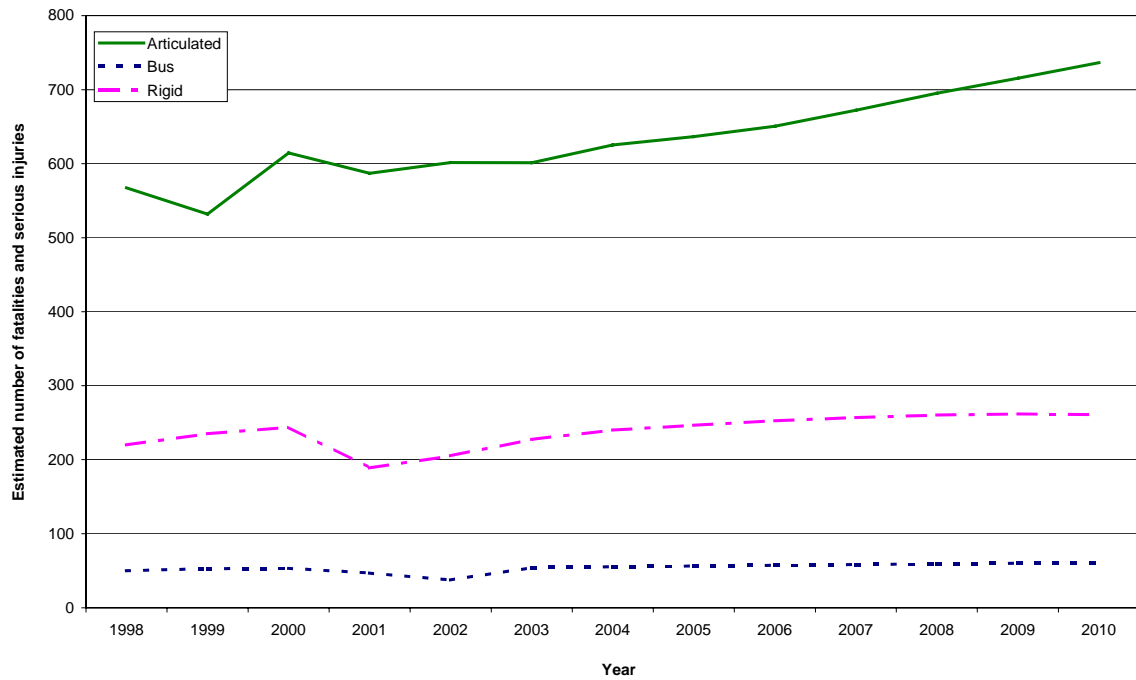
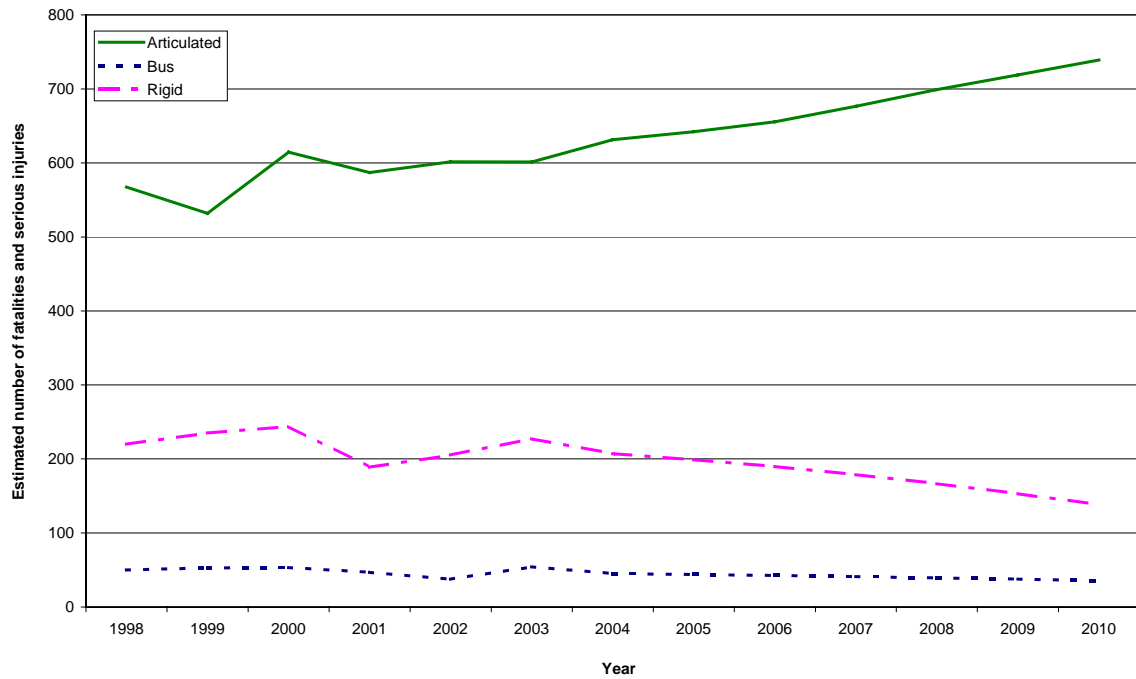


Figure 17. Estimated number of fatalities and serious injuries resulting from collisions between heavy vehicles and light passenger vehicles in non-metropolitan areas: Linear forecast of crash rates.



5.3 RESTRICTED ARTICULATED TRUCK TRAVEL

Given the relatively high crash rate experienced by articulated trucks in metropolitan areas and the relatively high severity of crashes involving articulated trucks, the impact of removing articulated trucks from the metropolitan area was considered. The workload of articulated trucks in metropolitan areas was transferred to rigid trucks through use of relative tonne-kilometre estimates for the two vehicle classes. The results are presented for the two crash rate scenarios in the following figures.

Figure 18. Estimated number of fatalities and serious injuries resulting from collisions between heavy vehicles and light passenger vehicles where articulated truck travel is restricted to non-metropolitan areas: 2003 crash rates maintained.

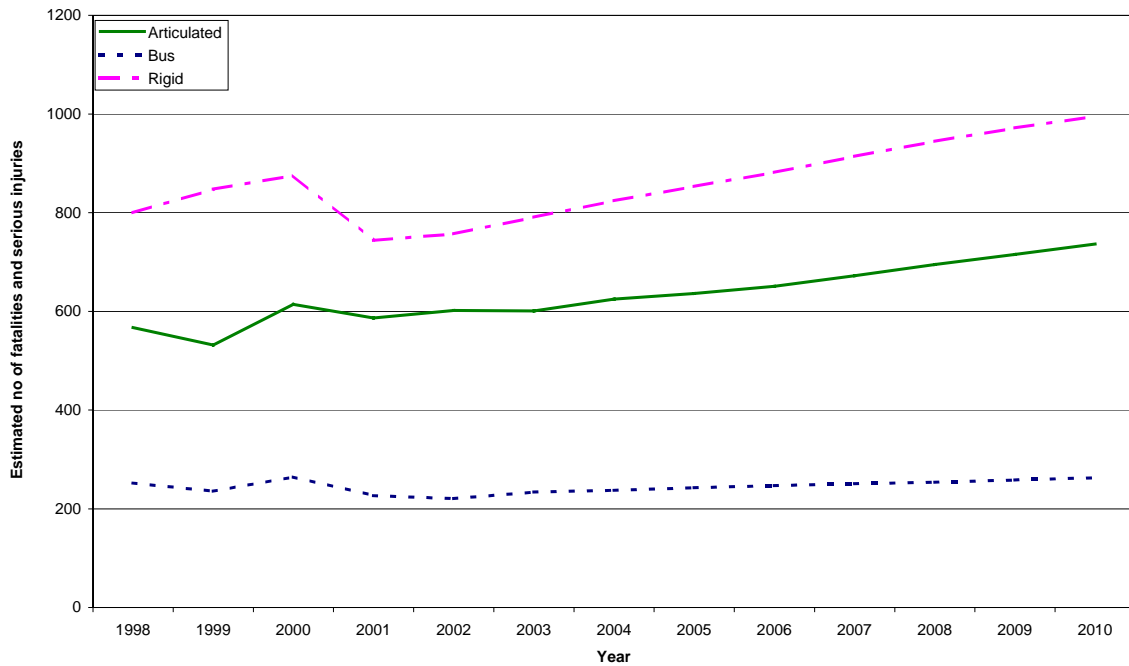
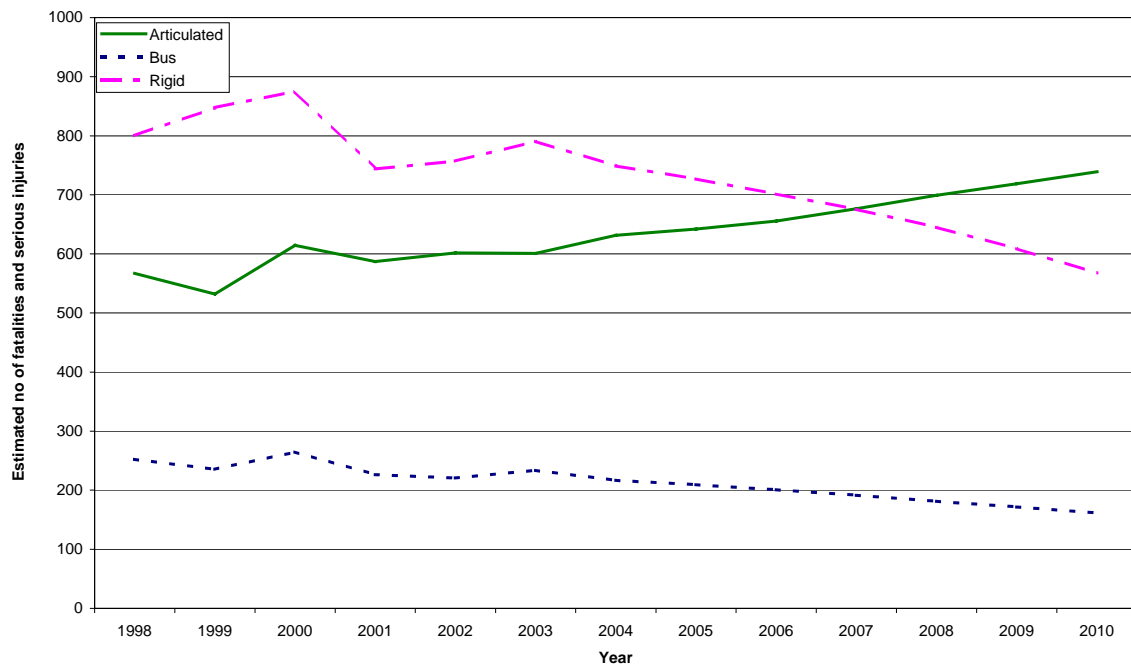


Figure 19. Estimated number of fatalities and serious injuries resulting from collisions between heavy vehicles and light passenger vehicles where articulated truck travel is restricted to non-metropolitan areas; Linear forecast of crash rates.

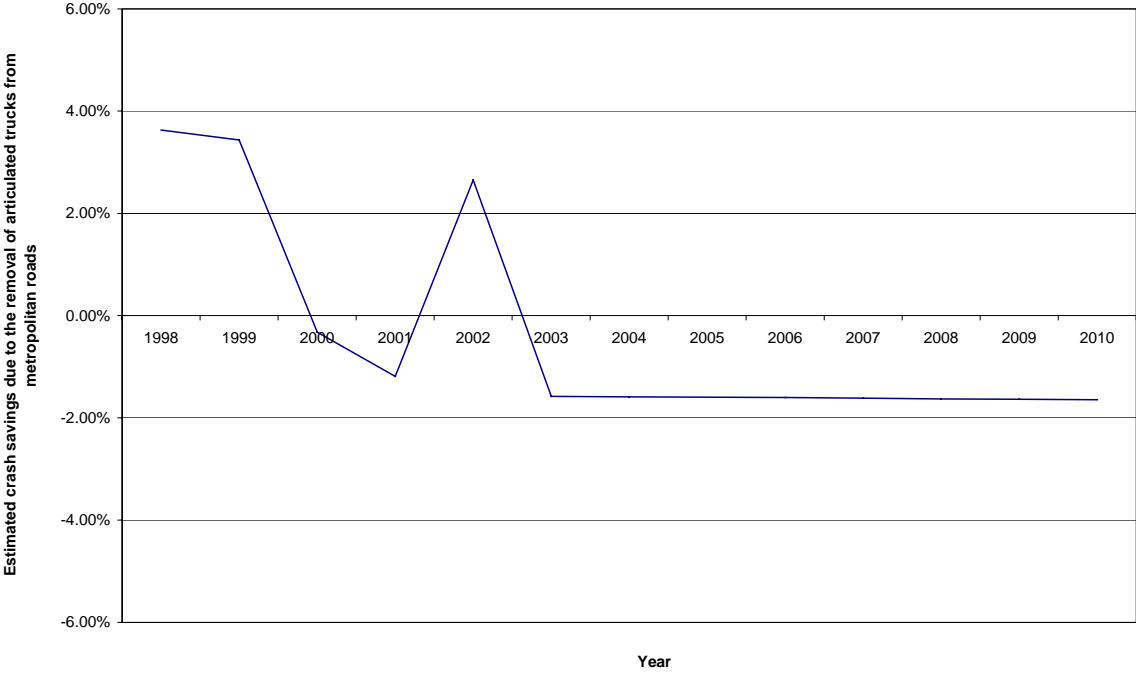


The level of articulated truck travel presented in the above scenarios is identical to that presented for non-metropolitan travel in Section 5.2.3 as there is no articulated truck travel in metropolitan areas in this circumstance. As a result, the estimates for articulated truck related fatalities and serious injuries are stable across the two scenarios for the reasons described in presenting the non-metropolitan analysis in Section 5.2.3. In contrast, there is variation in the estimated number of fatalities and serious injuries related to rigid truck travel.

To quantify the potential benefits of restricting articulated truck travel to non-metropolitan areas, the percentage difference between the forecasts presented in Section 5.2.1 (combined metropolitan and non-metropolitan travel with no restriction on articulated truck travel) and those presented above was calculated. The results for the two scenarios are presented below.

Under the scenario assuming 2003 crash rates are maintained, there is a marginal increase in the total number of fatalities and serious injuries incurred. This indicates that, the increase in the number of rigid trucks required to carry the load of articulated trucks in metropolitan areas, outweighs the benefit to be expected from removing articulated trucks from metropolitan areas.

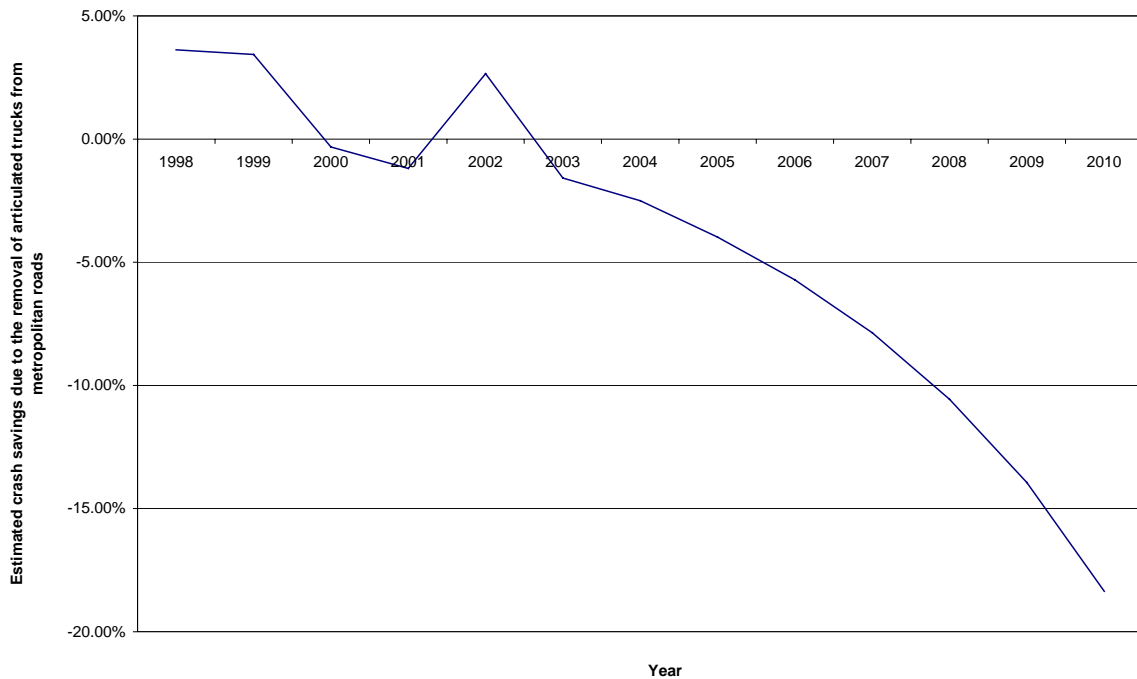
Figure 20. Estimated percentage crash savings due to the removal of articulated trucks from metropolitan roads: 1998-2010: 2003 crash rates maintained.



NB: Negative crash savings indicate an estimated crash increase

The elimination of articulated trucks from metropolitan areas also removes the impact of a dramatically declining crash rate for articulated vehicles in metropolitan areas on total road trauma under the second crash rate scenario (continuing trend of crash rate improvement). Under this scenario, the increase in the number of rigid trucks required to carry the load of articulated trucks in metropolitan areas, far outweighs the benefit to be expected from removing articulated trucks from metropolitan areas under this scenario. As a result there is estimated to be a significant rise in road trauma associated with removing articulated truck travel from metropolitan areas under this scenario. This scenario does, however, assume that the projected dramatic improvement in articulated truck crash rates would not be seen in the rigid trucks with which they were replaced. Instead, it assumes that the rigid trucks replacing the articulated trucks would have trends in crash rates in line with all other rigid trucks.

Figure 21. Estimated percentage crash savings due to the removal of articulated trucks from metropolitan roads: 1998-2010 (linear forecast of crash rates).



NB: Negative crash savings indicate an estimated crash increase

6 DISCUSSION

This study has attempted to quantify the effects of projected growth in heavy vehicle travel on the future levels of road trauma amongst drivers of light passenger vehicles. Instead of simply projecting past trends in light passenger driver road trauma, analysis has looked at each of three critical components of the road trauma chain: exposure to risk, crash risk per unit exposure and injury outcome per crash event. Approaching the analysis in this way produced a more robust estimate of future road trauma through explicitly modelling key factors leading to the road trauma outcome. It also allows a better understanding of the mechanism of projected road trauma trends associated with heavy vehicle travel which in turn can be used to target future heavy vehicle safety efforts. It is useful to consider each specific analysis input as well as how the specific form of each relates to the analysis outcomes.

The first key analysis input used for this project is the measure of heavy vehicle exposure in terms of total kilometres travelled. The BTRE estimates used for this study are the nationally recognised government estimates of past and predicted future heavy vehicle travel and hence appeared the best estimates for use in this study. Estimates of future total road trauma presented in this study depend heavily on the estimates of total exposure derived by the BTRE. Error in the predicted heavy vehicle travel trends will translate proportionately to error in the estimates of future road trauma. Clearly the BTRE projections represent the most likely future scenario based on current information however many unexpected things can alter demand for travel. Such things include changed economic circumstances such as an economic recession or further dramatic rises in fuel costs. Other government led initiatives like the provision of greater incentives for rail or sea transport could also greatly impact upon future heavy vehicle exposure. Whilst the modelling framework considered here has not considered the possible impacts of departures from the projected exposure curve, it could easily be adapted to do so.

The second important determinant of heavy vehicle related road trauma included as an input factor in the model developed is the estimated crash risk per heavy vehicle kilometre travelled. As noted, historical crash risk trends have been derived based on crash data from New South Wales inflated to national values using the estimates of the proportion of all crashes in Australia occurring in New South Wales. The use of New South Wales data was necessary as it was the only available state database with consistent and reliable reporting of tow-away and higher severity crashes where truck involved crashes are identified explicitly in the database. Using New South Wales as the basis for determining and projecting crash risk makes a number of assumptions. Key amongst these is that crash trends in New South Wales are representative of the national average and will remain so in the future in both relative and proportionate terms.

Average heavy vehicle crash rates estimated separately for metropolitan and non-metropolitan areas using the last six years of available data (1998 to 2003) show dramatic differences between the two areas. Articulated trucks, buses and rigid trucks all experience crash rates in metropolitan areas at least 2.5 times those experienced in non-metropolitan areas. The reasons for this difference are not investigated here but are most likely related to the relative complexity and congestion of the road environment. It is clear that primary safety for all three heavy vehicle types, whether due to vehicle or non-vehicle factors, is much less in metropolitan areas. Improvements in total road trauma levels could result from reductions in the particularly high metropolitan crash rates demonstrated in Figure 15. This figure shows a reduction in fatalities and serious injuries from light passenger vehicle collisions with articulated trucks of approximately 46%, primarily resulting from a predicted constantly declining crash rate over the period 2003 to 2010. The reductions in fatalities and serious injuries experienced due to declining crash rates are particularly strong for articulated trucks as crashes involving these vehicles are also particularly severe.

The influence of crash rates on predicted levels of heavy vehicle road trauma is also evident in the diverging estimates presented under the two crash rate scenarios considered in Section 4.2. Across all travel areas, metropolitan areas only and non-metropolitan areas only, where crash rates are assumed to remain constant at 2003 levels, heavy vehicle road trauma levels are predicted to increase. Under these scenarios all inputs to predicted road trauma levels remain constant except heavy vehicle travel. That is, the distribution of crashes by light passenger vehicle driver market group, heavy vehicle crash rates, and the crashworthiness of light passenger vehicles by driver market group remain constant whilst heavy vehicle travel is forecast to increase. It is therefore inevitable, that the number of fatalities and serious injuries experienced will rise. Under the alternative scenario, where crash rates are forecast to follow a downward linear trend over the forecast period, two inputs to predicted road trauma levels vary: crash rates and heavy vehicle travel. Given that across all travel areas, metropolitan areas only and non-metropolitan areas only, road trauma levels are predicted to fall, it is clear that the expected rise in vehicle travel is more than offset by the reductions in crash rates under this scenario. It is noted that the forecast decline in crash rates ranges between 27% for articulated trucks and 38% for rigid trucks over the period 2003 to 2010 and across all travel areas.

The two examples discussed above, illustrate the importance of the input variables and the interactions between them in determining the predicted level of heavy vehicle related road trauma. Therefore, in considering the scenario that is likely to most accurately represent future outcomes, the reliability of the input variables is relevant. In terms of heavy vehicle crash rates, it is perhaps unlikely that either of the scenarios presented in this report will be reflected over the coming years. Continuing efforts aimed at improving heavy vehicle safety and road safety in general make it unlikely that there will be no reduction in heavy

vehicle crash rates over the next five years. At the same time, it is likely to require substantial effort and investment to reduce heavy vehicle crash rates by the levels estimated under the alternative scenario. Nevertheless, the results of the two scenarios examined present likely possible boundaries of changes in total heavy vehicle related road trauma resulting from future growth in heavy vehicle travel. The actual level achieved will, in part, be influenced by the level of crash rate reductions achieved across all heavy vehicle classes.

From a policy perspective, this result highlights the importance of introducing and maintaining countermeasures and policies that continue to reduce heavy vehicle crash rates. Without these initiatives, the analysis predicts that forecast growth in heavy vehicle travel will result in an increasing road trauma burden on Australia related to heavy vehicle crashes.

The final critical input to the model of heavy vehicle related road trauma is the estimated crashworthiness of the light vehicle fleet by market group as a function of the heavy vehicle collision partner. As noted in Newstead et al (2004a), the estimates used in the model, whilst labelled crashworthiness, are a function both of the crashworthiness of the light passenger vehicle class and the aggressivity of each heavy vehicle class. The models predicting total road trauma have not accounted for change in either crashworthiness of the light vehicle fleet or aggressivity of heavy vehicles over time. Instead they have assumed crashworthiness and aggressivity remain static.

Estimates of crashworthiness by year of vehicle manufacture shown in Newstead et al (2005) suggest the crashworthiness of light passenger vehicles is likely to continue to show steady improvement over time. It is likely that this improvement will at least in part provide benefits in reducing road trauma in crashes with heavy vehicles beyond those estimated in this study. However, exactly how large the improvement in light vehicle crashworthiness in collisions with heavy vehicles will be is unclear. Less clear is whether changes in heavy vehicle aggressivity can be expected. Newstead et al (2004b) have shown aggressivity of the light passenger vehicle fleet has been static for many years, relating the lack of progress to a lack of design standards concerning aggressivity. A similar lack of change could also be expected for aggressivity in the heavy vehicle fleet which has also seen few changes in design regulations. Studies such as those by Lambert (2002) suggest, however, that significant reductions in heavy vehicle aggressivity could be achieved through better design principles potentially providing large reductions in total road trauma resulting from heavy vehicle crashes. This could provide an alternative or additional option to reduce road trauma, particularly if heavy vehicle crash rates cannot continue to be reduced.

A final subtlety concerning the crashworthiness estimates used in the models developed for this study is that they relate only to driver injury outcome. The reasons for this are discussed in both Newstead et al (2004a) and Newstead et al (2005) but relate to the unreliable reporting of uninjured passengers in police reported crash data. As such, the projections of road trauma made in this report relate only to light passenger vehicle drivers. The projections could be converted to cover all light vehicle occupants using average occupancy and injury rates in reported heavy vehicle crashes and assuming these remain constant over time. If occupancy rates increase, the relative benefits would be underestimated with the converse true for falling occupancy rates.

One scenario examined in this study as a possible solution to predictions of increases in heavy related fatalities and serious injuries is the removal of articulated trucks from

metropolitan areas. In metropolitan areas articulated trucks experience particularly high crash rates and result in particularly severe outcomes. Under this proposed solution additional rigid trucks would be introduced to carry the load previously carried by articulated trucks. Regardless of the crash rate scenario applied, this potential solution does not result in a reduction of heavy vehicle related road trauma. Indeed, road trauma could be expected to increase were articulated trucks to be replaced with rigid trucks in metropolitan areas. This outcome results from the increase in the number of rigid trucks required to complete the work of the articulated trucks no longer travelling in metropolitan areas. Despite the lower frequency and severity of rigid truck crashes in metropolitan areas compared to articulated truck crashes, the additional vehicle kilometres travelled required by rigid trucks to carry the same load negates any overall benefits to be obtained by switching vehicle types. This result suggests that replacing rigid trucks with fewer articulated trucks in metropolitan areas would serve to reduce the road toll. However, this may not be generally possible as articulated trucks do not offer the same manoeuvrability and general utility of rigid trucks in many circumstances where rigid trucks currently operate. It may also not be possible to arrange all freight logistics to be served by the higher capacity articulated trucks in an economically viable way.

Although only the one scenario has been considered for heavy vehicle fleet composition, the model developed in the study could be used to examine many others. The only real substitution in heavy vehicle composition that is practical, however, is the distribution between rigid and articulated trucks. As shown by the scenario considered, current practice within the constraints of practicality is probably not too far from the optimum. From the general results in the study, it would seem the most viable ways of reducing heavy vehicle related road trauma are to reduce either the heavy vehicle exposure, crash risk or both and to continue to improve light vehicle crashworthiness and reduce heavy vehicle aggressivity.

6.1 LIMITATIONS

This study aimed to build on previous work in the areas of vehicle fleet safety to examine the influence of growth in heavy vehicle travel on total road trauma levels associated with these vehicles. Whilst this study serves to extend the analysis beyond previous work in this area by proposing and applying a comprehensive deterministic numerical model there remain three key limitations associated with the data used in this study and the method adopted to estimate the influence on road trauma of growth in heavy travel. These limitations are discussed below.

1. **Forecasting Crash Rates:** The first limitation of this study is related to the method adopted to forecast growth in heavy vehicle travel and the associated changes in heavy vehicle crash rates. Two distinct forecasts scenarios are considered; the first assumes no change to the crash rate associated with each heavy vehicle class during the forecast period and the second assumes that crash rates for each heavy vehicle class follow a linear trend derived from the years immediately prior to the forecast period. Both of these scenarios estimate changes in heavy vehicle crash rates as a function of changes in heavy vehicle usage only. Changes in the usage of light passenger vehicles and the influence of such changes on heavy vehicle crash rates are not considered. Future work in this area would benefit from estimating future changes in light passenger vehicle travel, preferably by market group, and consideration of the combined influence of these changes and estimated changes in heavy vehicle travel on heavy vehicle crash rates for the three classes of heavy

vehicle identified in this study. This would ensure that changes in the exposure of heavy vehicle to light passenger vehicles, whether due to increased heavy vehicle travel, increased light passenger vehicle travel or some combination would be reflected in the estimates of future heavy vehicle related road trauma.

2. **Light Vehicle Driver Focus:** A second limitation of the model used to estimate changes in road trauma associated with heavy vehicle travel is that it considers the influence of heavy vehicle travel on light passenger vehicle drivers only. Consideration is not given to the influence of growth in heavy vehicle travel on other road users such as passengers travelling in light passenger vehicles, pedestrians, bicyclists, motorcyclists or heavy vehicle occupants themselves. Whilst the effects of heavy vehicle travel on these road users warrants investigation it was beyond the scope of this study.
3. **Generalisation of NSW Data:** The final relevant limitation to note is related to the data used to estimate heavy vehicle crash rates. As stated previously, crash rates are estimated using national estimates of heavy vehicle exposure and NSW crash data scaled to represent the national situation using national fuel sales data. This approach was adopted primarily on the basis of the available data, in particular the distinction between heavy vehicle types in the NSW crash data. However, by scaling NSW crash data to represent the national situation and hence to calculate national crash rates, it is assumed that proportional heavy vehicle exposure does not differ significantly across Australian States and Territories. An alternative to adopting this approach would be to obtain heavy vehicle exposure data for metropolitan and non-metropolitan areas of NSW and calculate crash rates for NSW only. National estimates of heavy vehicle road trauma could then be estimated based on the assumption that national heavy vehicle crash rates mirror those experienced in NSW. Consideration of the relative merit of this alternative approach is recommended for future work in this area.

In the event that NSW exposure data is unavailable on a metropolitan/non-metropolitan basis, future work should consider national trends in fatality crashes separately. Reliable national data concerning fatal crashes is available and trends in these crashes could act as a useful comparison for the trends in driver injuries provided in this study.

7 CONCLUSION

This study has been successful in building a model to project future trends in road trauma in the light passenger vehicle fleet as a result of crashes with heavy vehicles. The model has been developed to reflect three key elements of the road trauma chain: exposure, crash risk and injury outcome given crash involvement. BTRE projections of future heavy vehicle travel have been used to measure exposure whilst crash risk has been estimated from long term trends in heavy vehicle crashes in NSW combined with the BTRE exposure data. Injury outcome in a crash has been measured as a crashworthiness rating reflecting the risk of death or serious injury to light passenger vehicle drivers in collisions with various heavy vehicle classes.

Future heavy vehicle related road trauma trends have been projected based on two different scenarios of future crash risk. The first assumed heavy vehicle crash risk remained at 2003

levels whilst the second assumed crash rates continued to decline at a rate consistent with that observed from 1998 to 2003. Under the first scenario, road trauma associated with heavy vehicle crashes was predicted to increase in each year to 2010 for each heavy vehicle type but particularly for articulated trucks. Under the second scenario, increases in heavy vehicle travel were more than offset by projected improvements in heavy vehicle crash rates to produce estimated consistent falls in heavy vehicle related road trauma for each year to 2010. Similar trends were found when analysing metropolitan and rural trends separately. The only exception was that road trauma associated with articulated trucks was projected to rise in rural areas under both crash rate scenarios considered.

Although the results are limited by the available data and subject to a number of caveats, they are considered generally indicative of likely trends in future road trauma in the light vehicle fleet resulting from collisions with heavy vehicles for the projections considered. They highlight the importance of continuing to reduce heavy vehicle crash rates in the future to offset projected growth in heavy vehicle travel and hence deliver reductions in heavy vehicle related road trauma.

One major contribution of the study has been to define a methodology to study road trauma outcomes in the vehicle fleet by explicitly considering each component of the road trauma chain. In doing so, it has highlighted the key data items that are critical inputs to such a model. It has identified a number of these data items that need improved or enhanced collection on a national basis to produce more accurate estimates of road trauma outcomes from the model framework established.

8 QUALIFICATIONS AND ASSUMPTIONS

The results and conclusions presented in this report are based on a number of assumptions that the reader should note. In particular it has been assumed that:

- NSW Police reported crash data accurately identifies those crashes involving articulated trucks, rigid trucks or buses.
- Estimated crash rates for collisions between heavy vehicles and light passenger vehicles in NSW are representative of those experienced in other Australian states and territories.
- The distribution of heavy vehicle crashes by light passenger vehicle collision partner derived from NSW Police reported crash data is representative of the position in other Australian states and territories.
- Crashworthiness estimates for light passenger vehicles in collisions with heavy vehicle accurately reflect the average risk of driver death or serious injury experienced in these crash types.
- Estimates and forecasts of heavy vehicle travel for the period 1991 to 2010 provided by the BTRE are accurate.
- Definitions of the three heavy vehicle types are consistent across the different data sets used.

- Definitions of metropolitan and non-metropolitan areas are consistent across the different data sets used.

Important limitations of the research are documented in the Discussion section and should be noted.

9 REFERENCES

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APPENDIX A

Forecasted heavy vehicle crash rates for all areas, metropolitan areas and non-metropolitan areas.

ALL AREAS

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
<i>Articulated Truck</i>	1.89	1.85	1.86	1.66	1.69	1.58	1.53	1.47	1.41	1.34	1.28	1.21	1.15
<i>Bus</i>	3.68	3.26	3.66	3.01	2.98	2.95	2.74	2.60	2.45	2.30	2.16	2.01	1.86
<i>Rigid Truck</i>	1.61	1.62	1.61	1.35	1.30	1.33	1.21	1.13	1.06	0.98	0.91	0.83	0.75

METROPOLITAN AREAS

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
<i>Articulated Truck</i>	6.65	6.59	6.16	5.14	5.27	4.78	4.33	3.93	3.52	3.11	2.70	2.29	1.88
<i>Bus</i>	7.48	6.54	7.43	6.01	6.15	5.82	5.48	5.17	4.86	4.55	4.24	3.93	3.62
<i>Rigid Truck</i>	2.22	2.22	2.27	1.93	1.81	1.81	1.68	1.58	1.47	1.37	1.27	1.16	1.06

NON-METROPOLITAN AREAS

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
<i>Articulated Truck</i>	0.89	0.81	0.92	0.88	0.87	0.86	0.87	0.87	0.87	0.87	0.86	0.86	0.86
<i>Bus</i>	0.56	0.57	0.57	0.48	0.38	0.55	0.45	0.43	0.41	0.38	0.36	0.34	0.32
<i>Rigid Truck</i>	0.82	0.85	0.81	0.63	0.65	0.70	0.61	0.57	0.53	0.49	0.45	0.41	0.37

APPENDIX B

Estimates of Light passenger vehicle Crashworthiness by Market Group and Heavy Vehicle Collision Partner

ESTIMATION OF VEHICLE SAFETY RATINGS BY LIGHT PASSENGER VEHICLE MARKET GROUP AND HEAVY VEHICLE COLLISION PARTNER

1 CRASH DATA

Police reported crash data from Victoria, NSW, Queensland and Western Australia were used to produce the revised estimates of the crashworthiness of light passenger vehicles in collisions with heavy vehicles by market group of light vehicle and class of heavy vehicle. The data covers vehicles manufactured over the period 1964-2003 and crashing during the years 1987-2003 and is derived from that used to estimate the crashworthiness and aggressivity ratings of Newstead et al (2005b). The method for selecting appropriate cases from each data source is detailed below.

1.1 VICTORIAN CRASHES WITH HEAVY VEHICLES

Calculation of light passenger vehicle crashworthiness ratings by heavy vehicle collision partner and light vehicle market group required selecting light passenger vehicles involved in crashes with a heavy vehicle. Heavy vehicle identification was possible by examining the secondary vehicle type involved in the crash. Records were restricted to those where the secondary vehicles were one of semi-trailer, truck (excluding semi), bus/coach, mini-bus (9-13 seats). Semi-trailers were categorised as 'articulated', trucks as 'rigid truck' and bus/coach and mini bus as 'bus'. Light passenger vehicles considered were restricted to those manufactured over the period 1982 to 2003 as market group detail information was required and only available for these years of manufacture.

1.2 NEW SOUTH WALES CRASHES WITH HEAVY VEHICLES

Heavy vehicle identification in two-vehicle crashes was possible since each NSW crash record has variables identifying light truck, rigid truck, articulated truck and bus accidents. Light trucks and rigid trucks were categorised as 'rigid trucks'. Crash selection was restricted to those involving a light passenger vehicle manufactured over the period 1982 to 2003 that had identified market group details.

It was not possible to use the records from New South Wales data for 1999 to 2003 in the injury severity analysis as a reliable measure of injury severity, apart from the fatality-injury dichotomy, was not available for these years.

1.3 QUEENSLAND CRASHES WITH HEAVY VEHICLES

To identify light passenger vehicles involved in a collision with a heavy vehicle, a variable describing unit type was used to identify heavy vehicles and matched with the opposing vehicle record. This enabled vehicle occupant injury levels in the vehicle involved in the crash with the heavy vehicle to be obtained. Unit types coded as rigid truck, articulated vehicle and bus/coach were coded as 'rigid truck', 'articulated truck' and 'bus' respectively. These records were used for calculation of vehicle crashworthiness ratings when involved in a heavy vehicle collision. As with the data from NSW, the presence of uninjured drivers in the data file meant that the Queensland data was also suitable for measuring both the risk and severity of driver injury.

1.4 WESTERN AUSTRALIA CRASHES WITH HEAVY VEHICLES

Two-vehicle collisions involving a heavy vehicle were identified in the WA data using a variable describing unit type to identify heavy vehicles. This variable was then matched with the opposing vehicle record. Unit types described as truck & 1 trailer, prime mover and one trailer (semi-trailer) and road train (truck/ prime mover & 2+ trailers) were coded as 'articulated vehicle'. Truck and prime mover were coded as 'rigid truck' and bus as 'bus'. A variable describing body type was then used to eliminate those heavy vehicle records that had body types inappropriate for heavy vehicle classification. These records were used for calculation of crashworthiness injury risk and severity for light passenger vehicles involved in heavy vehicle collisions.

1.5 NEW ZEALAND CRASHES WITH HEAVY VEHICLES

Two-vehicle collisions involving a heavy vehicle were identified in the NZ data using one variable describing vehicle type and another describing body type to identify heavy vehicles and then match with the opposing vehicle record. Vehicles with vehicle type coded as truck and body type of either 'articulated T' or 'articulated truck' were coded as 'articulated vehicle'. Trucks with body type of 'flat-deck tru', 'flat-deck truck' or other truck were coded as 'rigid truck' and vehicles of the type bus or school bus were coded as 'bus'. These records were used for calculation of severity for light passenger vehicles involved in a heavy vehicle collision.

1.6 COMBINED CRASH DATA FROM THE FIVE JURISDICTIONS- COLLISIONS WITH HEAVY VEHICLES

Data from the four Australian states and New Zealand was combined to enable the estimation of crashworthiness ratings of light passenger vehicles involved in two-vehicle collisions involving heavy vehicles.

The data used to estimate injury risk covered 129,598 crash involved drivers from NSW, Queensland and Western Australia of whom 23,696 sustained an injury and 105,902 were uninjured. Data from Victoria and New Zealand were excluded from this analysis as data on uninjured drivers is unavailable. After excluding those cases in which the explanatory factors other than vehicle characteristics were missing a total of 72,179 driver crash involvements remained. Of these, 15,013 drivers were injured and 57,166 were not injured. The data used to estimate injury severity covered 19,373 injured drivers of whom 5,987 were killed or seriously injured. The remaining 13,753 sustained minor injuries. After excluding those cases in which the explanatory factors other than vehicle characteristics were missing a total of 12,930 injured drivers remained. Of these 3,746 were killed or seriously injured and 9,184 sustained minor injuries. NSW data from 1998 onwards was excluded from the injury severity analysis due to the lack of a reliable indicator of injury severity.

2 Methods

Estimates of vehicle crashworthiness were calculated using the logistic regression procedure described in detail in Newstead et al., 2005. These estimates were calculated across all areas and also separately by crash site location (metropolitan/rural). In order to obtain estimates of injury risk and injury severity unbiased by factors other than vehicle make and model a number of factors thought to influence the risk and severity of injury to

drivers were included in the logistic regression model. Table 2 details the main effects and interactions that were judged to be significant predictors of injury risk and injury severity through the stepwise logistic modelling approach. As estimates of crashworthiness were calculated across all regions and across metropolitan and rural areas separately, individual covariate models were estimated for each of the analyses.

Table 2. Significant factors in the logistic regression models of injury risk and injury severity by crash type.

	Metro/Rural		All Crashes	
Significant Model Factors	Injury Risk	Injury Severity	Injury Risk	Injury Severity
Main Effects	Driver age, Driver sex, State of crash, Year of crash	Driver age Driver sex State of crash Year of crash	Driver age, Driver sex, Speed zone, State of crash, Year of crash	Driver age Driver sex, Speed zone, State of crash Year of crash
First Order Interactions	state × year sex × state age × sex age × state	state × year	zone × state sex × state age × sex sex × zone zone × year state × year age × state	age × sex zone × state state × year

3 RESULTS

Injury risk, injury severity and crashworthiness ratings for each of the light passenger vehicle market groups and heavy vehicle collision partners considered are presented below for each of the crash locations (i.e. all locations, metropolitan and rural). Upper and lower confidence limits and confidence limit width for each estimated crashworthiness rating are also provided. The coefficient of variation shown is the ratio of the width of the confidence limit to the magnitude of the point estimate and is useful as a scaled measure of rating accuracy. Where insufficient data was available to estimate vehicle safety ratings, raw data detailing the injury outcome was used to provide an approximate value. Values estimated in this way are shaded in the tables.

Table 3. Estimated crashworthiness by light passenger vehicle market group and heavy vehicle collision partner: all crash locations.

Vehicle Market Group	Heavy Vehicle Type	Injury Risk	Injury Severity	CWR	Lower 95% CL	Upper 95% CL	CI Width	CoV
4WDC	Artic Truck			14.38%				
4WDC	Bus			3.07%				
4WDC	Rigid Truck	21.66%	32.62%	7.07%	5.24%	9.53%	4.28%	0.61
4WDL	Artic Truck	28.16%	38.65%	10.88%	7.47%	15.86%	8.39%	0.77
4WDL	Bus	14.03%	27.58%	3.87%	1.67%	8.99%	7.32%	1.89
4WDL	Rigid Truck	12.81%	23.84%	3.05%	2.25%	4.14%	1.88%	0.62
4WDM	Artic Truck			22.89%				
4WDM	Bus			1.44%				
4WDM	Rigid Truck	16.33%	12.87%	2.10%	1.11%	3.97%	2.86%	1.36
CU	Artic Truck	30.36%	31.27%	9.49%	7.29%	12.36%	5.07%	0.53
CU	Bus	17.04%	30.72%	5.24%	3.23%	8.48%	5.24%	1.00
CU	Rigid Truck	12.77%	25.10%	3.21%	2.78%	3.69%	0.91%	0.28
CV	Artic Truck	29.83%	29.44%	8.78%	5.31%	14.52%	9.21%	1.05
CV	Bus	21.74%	18.81%	4.09%	2.29%	7.31%	5.03%	1.23
CV	Rigid Truck	16.63%	28.27%	4.70%	3.92%	5.63%	1.71%	0.36
L	Artic Truck	23.67%	33.86%	8.01%	7.02%	9.14%	2.12%	0.26
L	Bus	19.61%	28.37%	5.56%	4.57%	6.78%	2.21%	0.40
L	Rigid Truck	18.55%	26.38%	4.89%	4.41%	5.43%	1.03%	0.21
LX	Artic Truck	21.14%	46.05%	9.73%	7.55%	12.56%	5.01%	0.51
LX	Bus	16.45%	19.62%	3.23%	1.82%	5.72%	3.90%	1.21
LX	Rigid Truck	16.68%	23.82%	3.97%	3.19%	4.94%	1.75%	0.44
M	Artic Truck	27.22%	35.83%	9.75%	8.14%	11.68%	3.54%	0.36
M	Bus	19.57%	27.17%	5.32%	3.97%	7.12%	3.14%	0.59
M	Rigid Truck	20.40%	28.60%	5.83%	5.16%	6.60%	1.44%	0.25
PM	Artic Truck	35.85%	36.26%	13.00%	8.15%	20.75%	12.60%	0.97
PM	Bus	19.44%	28.03%	5.45%	3.52%	8.44%	4.93%	0.90
PM	Rigid Truck	17.83%	25.31%	4.51%	3.67%	5.55%	1.88%	0.42
S	Artic Truck	24.63%	34.40%	8.47%	7.25%	9.90%	2.65%	0.31
S	Bus	19.41%	25.68%	4.98%	3.89%	6.38%	2.48%	0.50
S	Rigid Truck	22.15%	28.18%	6.24%	5.59%	6.97%	1.37%	0.22
SL	Artic Truck	26.52%	34.53%	9.16%	7.36%	11.40%	4.04%	0.44
SL	Bus	23.41%	33.34%	7.81%	5.81%	10.49%	4.67%	0.60
SL	Rigid Truck	24.53%	28.52%	6.99%	6.06%	8.07%	2.00%	0.29
SP	Artic Truck	18.80%	34.51%	6.49%	3.99%	10.56%	6.57%	1.01
SP	Bus	14.40%	24.27%	3.50%	1.64%	7.48%	5.84%	1.67
SP	Rigid Truck	21.38%	24.26%	5.19%	3.84%	7.00%	3.15%	0.61

Table 4. Estimated crashworthiness by light passenger vehicle market group and heavy vehicle collision partner: metropolitan crashes.

Vehicle Market Group	Heavy Vehicle Type	Injury Risk	Injury Severity	CWR	Lower 95% CL	Upper 95% CL	CI Width	CoV
4WDC	Artic Truck			3.51%				
4WDC	Bus			3.46%				
4WDC	Rigid Truck	15.82%	21.75%	3.44%	2.14%	5.54%	3.41%	0.99
4WDL	Artic Truck			11.98%				
4WDL	Bus			0.89%				
4WDL	Rigid Truck	10.07%	17.04%	1.72%	1.01%	2.92%	1.91%	1.11
4WDM	Artic Truck			10.00%				
4WDM	Bus			1.79%				
4WDM	Rigid Truck	11.98%	8.97%	1.07%	0.36%	3.25%	2.89%	2.69
CU	Artic Truck	25.43%	20.25%	5.15%	3.02%	8.80%	5.78%	1.12
CU	Bus	15.10%	15.01%	2.27%	1.02%	5.03%	4.00%	1.77
CU	Rigid Truck	10.13%	18.65%	1.89%	1.56%	2.30%	0.74%	0.39
CV	Artic Truck			8.88%				
CV	Bus	19.97%	12.89%	2.57%	1.31%	5.05%	3.74%	1.45
CV	Rigid Truck	13.26%	20.95%	2.78%	2.21%	3.49%	1.28%	0.46
L	Artic Truck	19.88%	28.23%	5.61%	4.60%	6.84%	2.24%	0.40
L	Bus	16.51%	27.34%	4.51%	3.65%	5.58%	1.93%	0.43
L	Rigid Truck	15.55%	19.29%	3.00%	2.63%	3.41%	0.78%	0.26
LX	Artic Truck	16.15%	41.86%	6.76%	4.64%	9.85%	5.22%	0.77
LX	Bus	13.44%	9.66%	1.30%	0.55%	3.07%	2.52%	1.94
LX	Rigid Truck	13.66%	16.40%	2.24%	1.66%	3.03%	1.37%	0.61
M	Artic Truck	21.33%	24.94%	5.32%	3.95%	7.16%	3.21%	0.60
M	Bus	16.20%	24.03%	3.89%	2.78%	5.46%	2.68%	0.69
M	Rigid Truck	16.70%	22.85%	3.82%	3.27%	4.45%	1.18%	0.31
PM	Artic Truck			8.33%				
PM	Bus	15.91%	19.93%	3.17%	1.81%	5.54%	3.73%	1.18
PM	Rigid Truck	14.38%	19.19%	2.76%	2.14%	3.56%	1.42%	0.51
S	Artic Truck	20.12%	25.01%	5.03%	3.97%	6.39%	2.42%	0.48
S	Bus	15.81%	19.20%	3.04%	2.25%	4.10%	1.85%	0.61
S	Rigid Truck	18.52%	22.52%	4.17%	3.66%	4.75%	1.08%	0.26
SL	Artic Truck	21.27%	25.11%	5.34%	3.76%	7.59%	3.83%	0.72
SL	Bus	20.29%	26.60%	5.40%	3.82%	7.62%	3.80%	0.70
SL	Rigid Truck	20.91%	21.67%	4.53%	3.79%	5.41%	1.62%	0.36
SP	Artic Truck	16.51%	28.82%	4.76%	2.46%	9.20%	6.74%	1.42
SP	Bus	24.74%	29.74%	7.36%	3.51%	15.42%	11.91%	1.62
SP	Rigid Truck	32.28%	20.30%	6.55%	4.51%	9.53%	5.02%	0.77

Table 5. Estimated crashworthiness by light passenger vehicle market group and heavy vehicle collision partner: rural crashes.

Vehicle Market Group	Heavy Vehicle Type	Injury Risk	Injury Severity	CWR	Lower 95% CL	Upper 95% CL	CI Width	CoV
4WDC	Artic Truck			23.64%				
4WDC	Bus			3.46%				
4WDC	Rigid Truck	39.27%	52.00%	20.42%	14.54%	28.66%	14.12%	0.69
4WDL	Artic Truck	31.53%	45.01%	14.19%	9.16%	21.98%	12.81%	0.90
4WDL	Bus			9.26%				
4WDL	Rigid Truck	19.27%	37.14%	7.16%	5.10%	10.05%	4.95%	0.69
4WDM	Artic Truck			38.50%				
4WDM	Bus			1.79%				
4WDM	Rigid Truck			6.36%				
CU	Artic Truck	38.94%	45.96%	17.90%	13.67%	23.43%	9.77%	0.55
CU	Bus			13.48%				
CU	Rigid Truck	18.89%	38.39%	7.25%	6.17%	8.53%	2.37%	0.33
CV	Artic Truck			13.11%				
CV	Bus			12.24%				
CV	Rigid Truck	24.59%	44.00%	10.82%	8.28%	14.13%	5.85%	0.54
L	Artic Truck	30.30%	45.42%	13.76%	11.90%	15.91%	4.01%	0.29
L	Bus	24.32%	17.19%	4.18%	2.42%	7.23%	4.81%	1.15
L	Rigid Truck	23.81%	41.52%	9.89%	8.74%	11.18%	2.44%	0.25
LX	Artic Truck	31.48%	56.01%	17.63%	12.91%	24.09%	11.18%	0.63
LX	Bus			15.58%				
LX	Rigid Truck	23.16%	38.83%	8.99%	6.62%	12.22%	5.60%	0.62
M	Artic Truck	38.69%	52.36%	20.26%	16.65%	24.64%	7.99%	0.39
M	Bus			9.75%				
M	Rigid Truck	27.90%	39.15%	10.92%	9.26%	12.88%	3.62%	0.33
PM	Artic Truck			32.82%				
PM	Bus			15.00%				
PM	Rigid Truck	25.65%	38.12%	9.78%	6.98%	13.69%	6.70%	0.69
S	Artic Truck	11.09%	49.93%	5.54%	3.52%	8.69%	5.17%	0.93
S	Bus			15.84%				
S	Rigid Truck	18.15%	38.82%	7.05%	5.86%	8.48%	2.62%	0.37
SL	Artic Truck	35.69%	50.53%	18.03%	14.10%	23.07%	8.97%	0.50
SL	Bus			13.64%				
SL	Rigid Truck	29.33%	41.80%	12.26%	9.99%	15.04%	5.05%	0.41
SP	Artic Truck			12.04%				
SP	Bus			5.00%				
SP	Rigid Truck	28.48%	31.89%	9.08%	6.08%	13.57%	7.49%	0.82